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**PREDICTION OF HYDRODYNAMICS AND CHEMISTRY
OF CONFINED TURBULENT METHANE - AIR FLAMES
IN A TWO CONCENTRIC TUBE COMBUSTOR**

by N. C. Markatos, D. B. Spalding and S. K. Srivatsa

CONCENTRATION, HEAT AND MOMENTUM LIMITED

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research center
Contract NASW - 3077



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16. Abstract A formulation of the governing partial differential equations for fluid flow and reacting chemical species in a two-concentric-tube combustor is presented. A numerical procedure for the solution of the governing differential equations is described and models for chemical-equilibrium and chemical-kinetics calculations are presented. The chemical-equilibrium model is used to characterize the hydrocarbon reactions. The chemical-kinetics model is used to predict the concentrations of the oxides of nitrogen. The combustor considered consists of two coaxial ducts. Concentric streams of gaseous fuel and air enter the inlet duct at one end; the flow then reverses and flows out through the outer duct. Two sample cases with specified inlet and boundary conditions are considered and the results are discussed.			
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TABLE OF CONTENTS

	<u>Page</u>
1. <u>INTRODUCTION</u>	1
1.1 The problem considered	1
1.2 Connexions with previous work	1
1.3 Purpose of the report	3
1.4 Layout of the report	3
2. <u>PHYSICAL AND MATHEMATICAL ANALYSIS</u>	5
2.1 Introduction	5
2.2 Physical Models	5
2.3 Governing differential equations	7
2.4 Boundary conditions	11
2.5 Auxiliary relations	13
2.6 The chemical-equilibrium model	16
2.7 Treatment of chemical kinetics	19
3. <u>THE NUMERICAL SOLUTION PROCEDURE</u>	23
3.1 Introduction	23
3.2 The grid and its numbering	24
3.3 The finite-difference equations	26
3.4 Solution of the finite-difference equations	40
3.5 Solution of the chemical-equilibrium equations	45
3.6 Solution of the chemical-kinetics equations	50
3.7 Solution of the auxiliary equations	52
3.8 Summary of the solution procedure	53
4. <u>FURTHER FEATURES OF THE CALCULATION PROCEDURE</u>	56
4.1 The treatment of wall boundaries	56
4.2 The treatment of the inner wall	57
4.3 The treatment of heat transfer	57
5. <u>THERMODYNAMIC AND ELEMENT DATA</u>	66
5.1 Element data	66

	<u>Page</u>
5.2 Thermodynamic data	66
6. <u>KINETICS DATA</u>	67
7. <u>RESULTS AND DISCUSSIONS</u>	68
7.1 Introduction	68
7.2 Computational details	68
7.3 Results of test case 1	70
7.4 Results of test case 2	74
7.5 Conclusions	91
8. <u>CONCLUDING REMARKS</u>	92
9. <u>REFERENCES</u>	94
10. <u>NOMENCLATURE</u>	96
<u>APPENDIX A - ORGANISATION OF THE NASCO II COMPUTER PROGRAM</u>	104
A.1 Introduction	104
A.2 Program structure	104
A.3 The problem-dependent subroutines, BLOCK DATA, MAIN, OUTPUT, PRINT and BOUND	110
A.4 The physical-model subroutines, SOURCE and WALL	118
A.5 The chemical-model subroutines, CHEM, SPECE and CALC	122
A.6 The computational subroutines, COEFF, CONST, FLOWM, ADJUST, GEOM, and TEST	128
A.7 The thermochemical property subroutines, REACT and HCPS	134

	<u>Page</u>
<u>APPENDIX B</u> - LISTING OF THE NASCO II COMPUTER PROGRAM	141
<u>APPENDIX C</u> - GLOSSARY OF FORTRAN VARIABLES	218
<u>APPENDIX D</u> - LISTING OF THE OUTPUT FROM THE NASCO II PROGRAM	242
<u>APPENDIX E</u> - UPDATE TO COMPUTE STANTON NUMBERS	270
ACKNOWLEDGEMENTS	284
REPORT DISTRIBUTION LIST	

1. INTRODUCTION

1.1 The problem considered

The problem considered in the present report involves the development of a general-purpose computer program for the realistic prediction of the hydrodynamics and chemical reaction in a two-concentric-tube combustor; special attention being given to pollutant (NO_x) formation.

The combustor geometry considered in this study is shown in Figure 1. As indicated in the Figure, concentric streams of fuel (methane) and air enter the inner duct of diameter $D_{1,i}$ and length L_1 . On entering the duct, the fuel and air mix together and at the end of the inner duct, the flow expands radially outward and flow reversal occurs into the passage of inner diameter $D_{2,i}$. Combustion occurs in the flow reversal region. Oxides of nitrogen and other combustion products are formed as a result of the chemical reaction.

The flow is two-dimensional, axisymmetric, steady and turbulent.

1.2 Connexions with previous work

The method of solution employed is based on Ref 1, which describes a general computer program (CHAMPION 2/E/FIX) for two-dimensional elliptic flows. While the solution procedure employed in the present work is basically the same as that of Ref 1, the computer program itself has been extensively modified in order to improve its structure, efficiency and comprehensibility. In addition, the present work has also involved the inclusion of heat transfer effects and of the appropriate chemical-equilibrium and kinetics-calculation schemes.

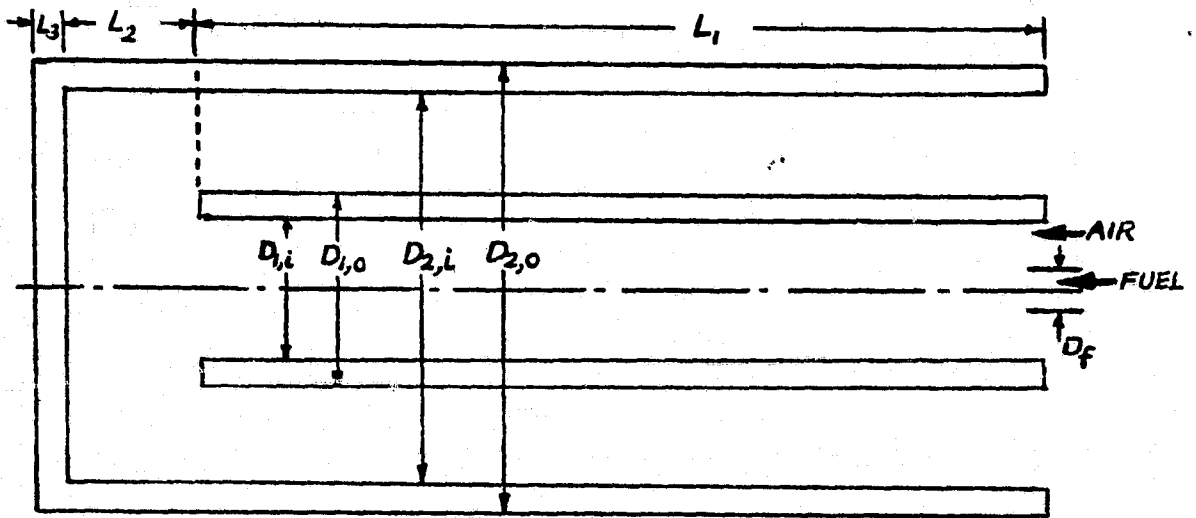


Figure 1: Geometry of a two-concentric- tube combustor (not to scale).

1.3 Purpose of the report

The purpose of this report is to present the analysis of the hydrodynamics and the chemical reaction in the two-concentric-tube combustor (Fig. 1). The analysis involves the mathematical formulation of the flow in terms of partial differential and some auxiliary algebraic equations. Subsequently these equations are cast in their finite-difference form for obtaining numerical solutions. The solution procedure is incorporated in a computer program to produce profiles of velocity, temperature, and species concentrations throughout the combustor.

This report provides all the necessary information concerning the mathematical modelling of the flows under consideration, it describes the numerical analysis involved in the solution of the relevant equations and it defines the user-orientated parts of the program.

It is to serve as both a comprehensive reference to the mathematics and numerical procedure used in the program and as an operational manual for the computer program.

1.4 Layout of the report

The remainder of this report is divided into ten chapters. Chapter 2 is concerned with the mathematical formulation and physical models employed in the solution procedure. Chapter 3 details the numerical solution procedure, and Chapter 4 describes further features of the calculation. Thermodynamic and element data are discussed in Chapter 5, and kinetics data in Chapter 6. Results and discussions are provided in Chapter 7, and Chapter 8 provides some concluding remarks. Relevant literature references and nomenclature are given in Chapters 9 and 10 respectively, which close this report. Appendices A and B contain the description

and the listing of the computer program. Appendix C contains a glossary of Fortran variables used in the computer program; and Appendix D contains a partial listing of the output from the program.

2. PHYSICAL AND MATHEMATICAL ANALYSIS

2.1 Introduction

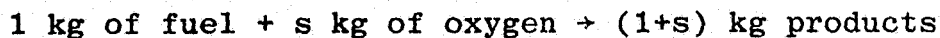
This Chapter describes the mathematical and physical basis of the problem considered. The physical modelling of properties and processes is discussed in Section 2.2. Section 2.3 outlines the conservation equations for mass, momentum, stagnation enthalpy, and chemical species. Boundary conditions are considered in Section 2.4. Auxiliary equations for mixture properties and flux calculations are dealt with in Section 2.5. Section 2.6 describes the chemical-equilibrium model, and Section 2.7 the chemical-kinetics model.

2.2 Physical Models

The conservation equations outlined in the next section are based on a physical model which involves certain assumptions regarding properties and processes; these are now described.

2.2.1 Processes

- (i) Axial and radial derivatives for conduction, diffusion, and momentum transport are included in the conservation equations.
- (ii) The chemistry incorporated into the computer code is as follows:
 - (1) A single-step reaction for hydrocarbon oxidation according to:



(1)

where s is a fixed stoichiometric ratio , and the rate of the reaction is governed by the Arrhenius relation:

$$\text{Rate} = C_1 T^{C_2} m_{\text{fu}}^{C_3} m_{\text{ox}}^{C_4} \exp (-C_5/T) \quad (2)$$

where C_1 , C_2 , C_3 , C_4 , and C_5 , are constants, T is the absolute temperature, and m_{fu} and m_{ox} are the concentrations of fuel and oxygen respectively.

- (2) The products of the above idealized reaction are assumed to consist of the species: CO , CO_2 , H_2O , O , H , H_2 , and OH , in such proportions as are appropriate to equilibrium stoichiometric adiabatic combustion at the prevailing pressure and enthalpy. These proportions are represented as algebraic functions of pressure and enthalpy; the constants in these functions being determined from interpolations in equilibrium computations made external and prior to the main computer code.
- (3) Oxides of nitrogen are calculated by reference to the kinetically-controlled reactions involving the species N_2 , O_2 , O , H , and OH . The scheme consists of nine reactions including the Zeldovich mechanism as shown in Section 2.7 below.

2.2.2 Properties

Transport-property assumptions are such as to allow a composite property ξ ($\equiv m_{\text{fu}} - m_{\text{ox}}/s$) to characterise the composition of the gas-mixture with respect to the products of combustion resulting from the main hydrocarbon oxidation reaction. The quantity ξ obeys a source-free conservation equation, and its transport coefficient is a function of position alone. This means that ξ is influenced by convection and diffusion alone; and underlying its definition

is the assumption that the transport properties of oxidant and fuel are everywhere equal.

2.3 Governing Differential Equations

The dependent variables are the axial velocity u , radial velocity v , pressure p , mixture fraction f , mass fraction of unburnt fuel m_{fu} , stagnation enthalpy $\hat{h}$ and the mass fractions of the species involved in the NO_x - reactions (i.e. NO , NO_2 , N , and N_2O). As mentioned earlier in Section 2.2.1, the concentrations of the species CO , CO_2 , H_2O , O , H , H_2 , and OH are determined by a chemical-equilibrium analysis, subsequent to the solution of the governing differential equations for f and m_{fu} .

The differential equations which govern the fluid flow for steady, two-dimensional axisymmetric flow are written* in cylindrical polar (x - r) coordinates as:

x -direction momentum equation:

$$\begin{aligned} \frac{\partial}{\partial x} (\rho u^2) + \frac{1}{r} \frac{\partial}{\partial r} (\rho r v u) - \frac{\partial}{\partial x} (\mu \frac{\partial u}{\partial x}) - \frac{1}{r} \frac{\partial}{\partial r} (r \mu \frac{\partial u}{\partial r}) \\ = - \frac{\partial p}{\partial x} + \frac{\partial}{\partial x} (\mu \frac{\partial u}{\partial x}) + \frac{1}{r} \frac{\partial}{\partial r} (r \mu \frac{\partial v}{\partial x}) \end{aligned} \quad (3)**$$

* Symbols are explained in the nomenclature (Chapter 10).

** In the equations presented here and later in the report, μ and Γ are the effective transport coefficients; the subscript 'eff' is however largely omitted for the sake of convenience.

r-direction momentum equation:

$$\begin{aligned} \frac{\partial}{\partial x} (\rho u v) + \frac{1}{r} \frac{\partial}{\partial r} (\rho r v^2) - \frac{\partial}{\partial x} (\mu \frac{\partial v}{\partial x}) - \frac{1}{r} \frac{\partial}{\partial r} (r \mu \frac{\partial v}{\partial r}) \\ = - \frac{\partial p}{\partial r} + \frac{\partial}{\partial x} (\mu \frac{\partial u}{\partial r}) + \frac{1}{r} \frac{\partial}{\partial r} (r \mu \frac{\partial v}{\partial r}) - \frac{2 \mu v}{r^2} \end{aligned} \quad (4)$$

Continuity equation:

$$\frac{\partial}{\partial x} (\rho u) + \frac{1}{r} \frac{\partial}{\partial r} (\rho r v) = 0 \quad (5)$$

Conservation equation for chemical species j

$$\frac{\partial}{\partial x} (\rho u m_j) + \frac{1}{r} \frac{\partial}{\partial r} (\rho r v m_j) - \frac{\partial}{\partial x} (\Gamma_j \frac{\partial m_j}{\partial x}) - \frac{1}{r} \frac{\partial}{\partial r} (\Gamma_j r \frac{\partial m_j}{\partial r}) = R_j \quad (6)$$

where m_j is the mass fraction of chemical species j and R_j is the mass rate of creation of species j by chemical reaction.

Conservation equation for stagnation enthalpy $\tilde{h}$:

$$\frac{\partial}{\partial x} (\rho u \tilde{h}) + \frac{1}{r} \frac{\partial}{\partial r} (\rho r v \tilde{h}) - \frac{\partial}{\partial x} (\Gamma_{\tilde{h}} \frac{\partial \tilde{h}}{\partial x}) - \frac{1}{r} \frac{\partial}{\partial r} (\Gamma_{\tilde{h}} r \frac{\partial \tilde{h}}{\partial r}) = S_{\tilde{h}} \quad (7)$$

where $S_{\tilde{h}}$ represents the sum of all the source terms for $\tilde{h}$ and includes sources of radiation and heat fluxes at the walls of the duct. To arrive at equation (7), the assumption has been made that the exchange coefficients for the transport of the mixture and that for heat conduction are all equal at a point, although they may vary from point to point.

Conservation equation for mixture fraction f:

$$\frac{\partial}{\partial x} (\rho u f) + \frac{1}{r} \frac{\partial}{\partial r} (\rho r v f) - \frac{\partial}{\partial x} (\Gamma_f \frac{\partial f}{\partial x}) - \frac{1}{r} \frac{\partial}{\partial r} (\Gamma_f r \frac{\partial f}{\partial r}) = 0 \quad (8)$$

where the mixture fraction f is defined as

$$f = (\xi - \xi_{ox}) / (\xi_{fu} - \xi_{ox}) \quad (9)*$$

General form of governing differential equations:

Equations (3) to (8) may be written in a general form as:

$$\frac{\partial}{\partial x} (\beta u \phi) + \frac{1}{r} \frac{\partial}{\partial r} (r \beta v \phi) - \frac{\partial}{\partial x} (\Gamma_{\phi} \frac{\partial \phi}{\partial x}) - \frac{1}{r} \frac{\partial}{\partial r} (\Gamma_{\phi} r \frac{\partial \phi}{\partial r}) = S_{\phi} \quad (10)$$

In the above equation ϕ identifies the dependent variable, β is identically equal to either the mixture density ρ or zero; Γ_{ϕ} is the appropriate exchange coefficient for the variable ϕ ; and S_{ϕ} is the source term which includes both the sources of ϕ (positive or negative) and any other terms which cannot find a place on the left-hand side of the equation. Table 1 summarizes the equations in the form that are solved in the present work. Some notes about these equations now follow:

- The terms involving the velocity divergence ($\text{div } \vec{V}$) in the source terms of the x- and r-momentum equations have been ignored. For uniform-density (i.e. inert) flows $\text{div } \vec{V}$ is identically zero and there is no error involved. For the chemically reacting flows to be handled in the present work, $\text{div } \vec{V}$ is expected to be small compared to other terms in the momentum equations, and its omission will introduce small errors only.

* Note: $\xi_{ox} = (-m_{ox})_{inlet}/s$ and $\xi_{fu} = (m_{fu})_{inlet}$,

where m_{ox} is the oxygen mass fraction in the incoming oxidant stream and m_{fu} is the fuel mass fraction in the incoming fuel stream.

Table 1. Summary of Equations

Equation	ϕ	β	Γ_ϕ	S_ϕ
Continuity, Eq. (5)	1	ρ	0	0
x-momentum, Eq. (3)	u	ρ	μ	$-\frac{\partial p}{\partial x} + \frac{\partial}{\partial x} (\mu \frac{\partial u}{\partial x}) + \frac{1}{r} \frac{\partial}{\partial r} (r \mu \frac{\partial v}{\partial x})$
r-momentum, Eq. (4)	v	ρ	μ	$-\frac{\partial p}{\partial r} + \frac{\partial}{\partial x} (\mu \frac{\partial u}{\partial r}) + \frac{1}{r} \frac{\partial}{\partial r} (r \mu \frac{\partial v}{\partial r}) - \frac{2\mu v}{r^2}$
Fuel mass fraction, Eq.(6)	m_{fu}	ρ	μ/Sc_{fu}	Rate from equation(2).
Mixture fraction, Eq.(8)	f	ρ	μ/Sc_f	0.
NO _x -species, Eq. (6)	m_j	ρ	μ/Sc_j	Rate from equation (43).
Stagnation enthalpy, Eq.(7)	$\tilde{h}$	ρ	$\mu/Pr \tilde{h}$	0 (except for boundary fluxes; see section 4.3).

- Since the flow is turbulent, time-average values of flow variables and effective values of the exchange coefficients must be used.

2.4 Boundary conditions

Boundary conditions are required for the dependent variables at all the boundaries of the flow domain. These are now discussed below.

2.4.1 Inlet boundary

(a) u-velocity : The inlet u-velocities of the fuel and air streams are obtained from their specified mass flow rates via the continuity relations:

$$u_{fo} = \frac{m_{fo}}{\rho_{fuel} \left(\frac{\pi}{4} D_f^2 \right)} \quad (11)$$

$$u_{ao} = \frac{m_{ao}}{\rho_{air} \frac{\pi}{4} (D_{1,i}^2 - D_f^2)} \quad (12)$$

(b) v-velocity : The inlet v-velocity is assumed to be zero.

(c) Pressure : The inlet pressure is assumed uniform at the specified value of P_o .

(d) Chemical species and mixture fraction : In the inlet fuel stream, the fuel mass fraction (and mixture fraction) is set to unity; all other species mass fractions are set to zero. In the inlet air stream, the oxygen mass fraction is set to 0.232, and the nitrogen mass fraction to 0.768; all other species mass fractions (and mixture fraction) are set to zero.

(e) Stagnation enthalpy : The inlet stagnation enthalpy in the fuel and air streams is calculated from the specified inlet temperature and mixture composition by the equations given in Section 5.2.

2.4.2 Outlet boundary

(a) u-velocity : The outlet boundary condition for u-velocity is assumed to be that of zero axial gradient, i.e.

$$\frac{\partial u}{\partial x} = 0 \text{ at the exit} \quad (13)$$

(b) v-velocity : The outlet v-velocity is assumed to be zero, this follows from the outlet boundary condition on u-velocity.

(c) Pressure : For pressure, an outlet boundary condition of uniform pressure is employed.

(d) Chemical species, mixture fraction and stagnation enthalpy :

The outlet boundary condition for chemical species, mixture fraction and stagnation enthalpy is again assumed to be that of zero axial gradient, i.e.

$$\left. \begin{array}{l} \frac{\partial m_j}{\partial x} = 0 \\ \frac{\partial f}{\partial x} = 0 \\ \frac{\partial \hat{h}}{\partial x} = 0 \end{array} \right\} \text{ at the exit} \quad (14)$$

$$\left. \begin{array}{l} \frac{\partial m_j}{\partial x} = 0 \\ \frac{\partial f}{\partial x} = 0 \\ \frac{\partial \hat{h}}{\partial x} = 0 \end{array} \right\} \text{ at the exit} \quad (15)$$

$$\left. \begin{array}{l} \frac{\partial m_j}{\partial x} = 0 \\ \frac{\partial f}{\partial x} = 0 \\ \frac{\partial \hat{h}}{\partial x} = 0 \end{array} \right\} \text{ at the exit} \quad (16)$$

2.4.3 Axis of symmetry

At this boundary, a condition of zero radial gradient is assumed

for all dependent variables except the v-velocity which is set to zero.

2.4.4 The wall boundaries

The treatment of wall boundaries is discussed in Chapter 4 after the finite-difference equations have been derived in Chapter 3. The reason is that the treatment of the wall boundaries requires reference to the finite-difference equations.

2.5 Auxiliary Relations

In this section some auxiliary relations, and the assumptions associated with their use are introduced. These relations are used for the calculation of fluxes and certain properties.

2.5.1 Flux laws

Implicit in the differential equations given in Section 2.3 are the flux laws for the transport of momentum, mass and heat. These laws will now be summarised, for laminar and turbulent flows.

(a) Laminar transport properties:

- (i) Viscosity: Newton's law of viscosity for momentum transfer, relating the shear stress τ to the local velocity gradient, through the laminar viscosity, μ , can be expressed for simple flows as:

$$\tau = \mu(\partial u / \partial y) \quad (17)$$

- (ii) Diffusion coefficient: Fick's law of diffusion for mass transfer, relating the diffusion mass flux J_j , to the concentration gradient, through the exchange

coefficient, Γ_j , has the form:

$$J_j = -\Gamma_j (\partial m_j / \partial y), \text{ for the species } j \quad (18)$$

The diffusion coefficient Γ_j is obtained from the definition of Schmidt number. Thus,

$$\Gamma_j = \mu / Sc_j \quad (19)$$

It has been assumed in the solution procedure that the Schmidt numbers for fuel and oxygen (and all the other species) are equal to each other, and also uniform throughout the flow field.

(iii) Thermal conductivity: Fourier's law of heat conduction, relating the heat flux Q to the temperature gradient, through the exchange coefficient, Γ_h^λ , can be written as:

$$Q = -\Gamma_h^\lambda c (\partial T / \partial y) \quad (20)$$

where c stands for the constant-pressure specific heat of the local gas mixture.

In the present analysis, Γ_h^λ is obtained from a knowledge of the mixture viscosity μ and the laminar Prandtl number:

$$\Gamma_h^\lambda = \mu / Pr_h^\lambda \quad (21)$$

In general, the laminar Prandtl number (or the exchange coefficient Γ_h^λ itself) can, if desired, be specified as any arbitrary function of temperature and composition; this will make Γ_h^λ depend upon temperature and composition in a way different from μ .

(b) Turbulent transport properties:

For a realistic modelling of the flow, the effect of turbulence has to be included whenever appropriate. The scope of the present contract does not permit the treatment of turbulence by means of a sophisticated model. Instead a simply zero-equation model of turbulence is employed.

- (i) Viscosity: The turbulent shear stresses are linked to the local velocity gradient through a laminar-like stress-strain law:

$$\tau = \mu_{\text{eff}} \left| \frac{\partial u}{\partial y} \right| \quad (22)$$

For the present work, the effective viscosity is assumed to be uniform throughout the flow field. This uniform value is obtained from an empirical relation which gives a value of μ_{eff} of the same order as expected in flows of the type under consideration:

$$\mu_{\text{eff}} = \frac{0.12(m_{fo} + m_{ao})}{D_{1,i}} \quad (23)$$

where m_{fo} and m_{ao} are the inlet fuel and air mass flow rates and $D_{1,i}$ is the inner diameter of the inner tube.

- (ii) Diffusion coefficient and thermal conductivity: The effective diffusion coefficients for the transfer of mass and energy are obtained from the definitions of Schmidt and Prandtl numbers respectively.

$$\text{Thus, for mass transfer, } \Gamma_{\text{eff}} = \mu_{\text{eff}} / \text{Sc}_{\text{eff}} \quad (24)$$

$$\text{and for heat transfer, } \Gamma_{\text{eff}} = \mu_{\text{eff}} / \text{Pr}_{\text{eff}} \quad (25)$$

2.5.2 Temperature of the mixture

The temperature of the mixture, T , at a given point in the flow field, is obtained from known local values of the stagnation enthalpy $\tilde{h}$ and the composition of the mixture as follows:

$$\tilde{h} = \sum_{j=1}^{NS} m_j h_j \quad (26)$$

where the species enthalpy h_j is obtained by the method described in Section 5.2 on thermodynamic data. The fluid temperature is then obtained as described in Section 5.2.

2.5.3 The ideal-gas equation of state

For a given temperature, the pressure and the density are assumed to be related through the ideal gas-equation:

$$p = \frac{\rho RT}{\bar{W}} \quad (27)$$

where $\bar{W}$, the mean molecular weight of the gas mixture, is given by

$$\bar{W} = 1 / \sum_{j=1}^{NS} (m_j / W_j) \quad (28)$$

2.6 The Chemical-Equilibrium Model

2.6.1 Introduction

The chemistry involved in the hydrocarbon-oxidation process (Sec. 2.2.1) will now be described. The oxidation reaction is assumed to be a single-step one and results in some product species. These species are in chemical equilibrium at the prevailing pressure and enthalpy. Their concentrations are obtained from a model which is based on the minimization of Gibbs free energy. The method

has been described by Gordon and McBride (Ref. 2).

2.6.2 Species considered

The equilibrium products of combustion are considered to consist of the following species: CO, CO₂, H₂O, O, H, H₂, and OH, together with unburnt O₂ and CH₄, and N₂. The last of these is assumed to be inert in the equilibrium reactions.*

2.6.3 Equations of chemical-equilibrium

The chemical-equilibrium equations to obtain the concentrations of the equilibrium-product-species have been discussed in detail in Ref. 2. Here the basis of their derivation will be only briefly described. The condition of chemical equilibrium is the minimization of Gibbs free energy subject to the following constraints: (a) mass balance for the elements present in the system; (b) specified enthalpy and (c) specified pressure. Since the resulting equations are not all linear, they have to be solved by an iterative procedure. The numerical method of solution of these equations is described in Section 3.5. Here the basic steps for obtaining the chemical-equilibrium composition are considered.

2.6.4 Procedure for obtaining chemical-equilibrium compositions

The basic steps for obtaining the concentrations of the species CO, CO₂, H, H₂, H₂O, O, and OH are:

- The stagnation enthalpy, $\hat{h}$, the mixture fraction, f , and the mass fraction of unburnt fuel, m_{fu} , are obtained

* N₂ is of course not inert in the NO_x-formation reactions; but these will be treated separately (Sec. 2.7).

from the solution of the respective partial differential equations (7, 8, and 6).

- The mass fraction of unburnt oxygen, m_{ox} , is obtained from:

$$m_{ox} = (m_{fu} - \frac{f - f_{st}}{1 - f_{st}})s \quad (29)$$

where f_{st} is the stoichiometric value of f . Should the value of m_{ox} be less than zero, during the iterative solution, it is set equal to zero (or a small quantity for programming convenience).

- The mass fraction of the equilibrium-product-species m_{pr} , is given by:

$$m_{pr} = (f - m_{fu}) (1 + s) \quad (30)$$

- The mass fraction of nitrogen, m_{N_2} , is given by:

$$m_{N_2} = 1 - m_{fu} - m_{ox} - m_{pr} - \sum_j m_j \quad (31)$$

where the summation is carried out over the species N, NO, NO₂, and N₂O which are determined through rate-controlled reactions.

- The enthalpy of the equilibrium-product-species, h_{pr} , is then:

$$h_{pr} = \{\hat{h} - \sum_j h_j m_j\} / m_{pr} \quad (32)$$

where the summation is over all species other than the equilibrium-product-species (CO , CO_2 , H , H_2 , H_2O , O , and OH).

- For a given value of enthalpy (h_{pr}) and pressure the equilibrium-product-species concentrations for stoichiometric adiabatic combustion are obtained by means of interpolations using polynomial fits* in accordance with the method described in Section 3.5.4. These concentrations are then multiplied by a factor so that they add to m_{pr} , i.e.

$$m_{\text{CO}} + m_{\text{CO}_2} + m_{\text{H}} + m_{\text{H}_2\text{O}} + m_{\text{O}} + m_{\text{OH}} = m_{\text{pr}} \quad (33)$$

- At this stage, the mass fractions of all species except the pollutant-species N , NO , NO_2 , and N_2O have been determined. Since the latter are present in small amounts the values of these from the previous iterative sweep are used, and the temperature of the mixture obtained as per Section 3.7.
- The next step is the determination of the mass fractions of the pollutant species N , NO , NO_2 , and N_2O . This is considered in the following section.

2.7 Treatment of Chemical-Kinetics

2.7.1 Introduction

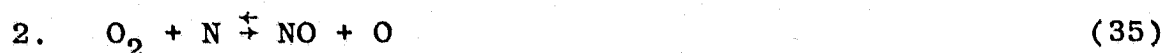
Oxides of nitrogen are formed during the course of combustion

* The determination of the polynomial coefficients is done external and prior to the main computer code.

reactions involving air as oxidant. These species are considered separately from the equilibrium species since their formation is governed by much slower kinetically-controlled reactions. The determination of the concentrations of these pollutant species involves a treatment of chemical-kinetics. This is discussed in the following sub-sections.

2.7.2. Species and reactions

The chemistry involved in the formation of nitrogen oxides will now be described. The model employed incorporates one of the simplest and most widely used mechanisms for calculations involving nitric oxide formation, namely the Zeldovich mechanism:



In addition to the above two reactions, the following reactions with the species N_2 , O_2 , O , H , and OH may be involved in the formation of the oxides of nitrogen, and are considered in the present work:





The choice of these reactions is based on a study of published literature (e.g. Ref. 6). Although some of these reactions have large rate constants, they usually involve species which are present in very small concentrations; hence their contribution towards the formation of nitric oxide is often small compared to that of reactions (1) and (2). Under fuel-rich conditions, reaction (3) may be significant.

2.7.3. The chemical-kinetics equations

The chemical-kinetics equations have been discussed in detail in Ref. 3. These equations are used to determine the concentrations of the pollutant species. Here the equations will be only briefly described. The conservation equation for species j has been given in Section 2.3 (equation 6). Attention is now centred on the source-term in this equation.

The source S_j of species j is the mass rate of creation of species j by chemical reaction and is given by:

$$S_j = \sum_{j=1}^M (\alpha'_{ij} - \alpha''_{ij}) (R_j - R_{-j}) \quad (43)$$

The forward rate, R_j of reaction j , is given by the Arrhenius expression:

$$R_j = 10^{B_j} T^{N_j} \exp(-T_{\text{act}j}/T) (\rho \sigma_m)^{\bar{\alpha}_j} \prod_{k=1}^{NS} (\rho \sigma_k)^{(\alpha'_{kj} - \alpha''_{kj})} \quad (44) *$$

* See nomenclature for explanation of symbols.

The backward rate, R_{-j} of reaction j , is given by a similar expression.

In the calculation of rates of production of N , NO , NO_2 , and N_2O by means of the above equations, the concentrations of the other species (which have already been determined by a chemical-equilibrium analysis) are assumed to remain unchanged. The justification for this assumption is that these species are mainly produced by reactions which are considerably faster than those involving NO_x production; therefore, the amounts of these species consumed (or produced) by the NO_x - reactions are negligible. The numerical method of solution of the species-conservation equation (6) is presented in Section 3.6.

2.7.4 Procedure for obtaining chemical-kinetics compositions

The steps for obtaining the concentrations of the species N , NO , NO_2 , and N_2O , are:

- The variables u , v , $\tilde{h}$, m_{fu} , m_{ox} , and the mass fractions of the chemical-equilibrium products are first obtained (Section 2.6.4).
- The species-conservation equations are solved to obtain the mass fractions of N , NO , NO_2 , and N_2O .
- The mass fraction of nitrogen, m_{N_2} , is adjusted so that all the species mass fractions add to unity.

$$m_{N_2} = 1 - \sum_j m_j, \quad j = 1, NS \text{ except for } N_2. \quad (45)$$

3. THE NUMERICAL SOLUTION PROCEDURE

3.1 Introduction

From the preceding sections it is seen that the differential equations under consideration are all non-linear and coupled together. For the flow under consideration there is no possibility for obtaining analytical solutions to them, and numerical methods have to be used. In this case a finite-difference technique is used which combines the main features of the SIMPLE algorithm of Patankar and Spalding (4) and the NEAT algorithm of Spalding (5); these features include:-

- solution of a sufficiently-general single form of differential equations;
- use of pressure and velocities as the main hydrodynamic variables;
- use of the pressure-correction technique for satisfying the continuity equation;
- provision for use of non-uniformly spaced grids;
- use of staggered storage locations for velocities;
- derivation of finite-difference equations by integrating the differential equations over finite control volumes;
- use of an upwind-differencing scheme for convection terms and a central-differencing scheme for diffusion terms;
- enforcing of reciprocity of convection and diffusion fluxes through common walls of adjacent cells;

- line-by-line solution of the finite-difference equations;
- updating of all dependent variables, in sequence, on a line; and
- frequent adjustment of velocities and pressures in order to ensure the satisfaction of overall mass conservation and overall momentum conservation, across sections.

3.2 The finite-difference grid

3.2.1 The cross-stream arrangement

The values of the fluid properties are calculated on a grid of which the nodes lie at constant values of the axial distance x and the radial distance r . Fig. 2 shows how the r -coordinate stretches from the value 0 at the symmetry axis to the value R at the wall of the duct. Between $r=0$ and $r=R$ lie $NY-2$ "grid points", i.e. arbitrarily chosen locations at which the ϕ values are computed; these are indicated by ●'s along the base of Fig. 2, through which pass vertical full lines. NY is the total number of r nodes, including the boundary values 0 and R .

Halfway between adjacent pairs of grid points in the range 2 to $(NY-1)$ are drawn vertical broken lines, dividing the whole r range into $(NY-2)$ intervals. The value of any dependent variable ϕ is supposed to be uniform within the interval; the fact is illustrated by the step-like ϕ -distribution of Fig. 2; the horizontals stretch from one broken line to the next.

The ϕ 's in these intervals are distinguished by subscripts: $\phi_2, \phi_3, \dots, \phi_{i-1}, \phi_i, \phi_{i+1}, \dots, \phi_{NY-2}, \phi_{NY-1}$. The boundary values are ϕ_1 and ϕ_{NY} .

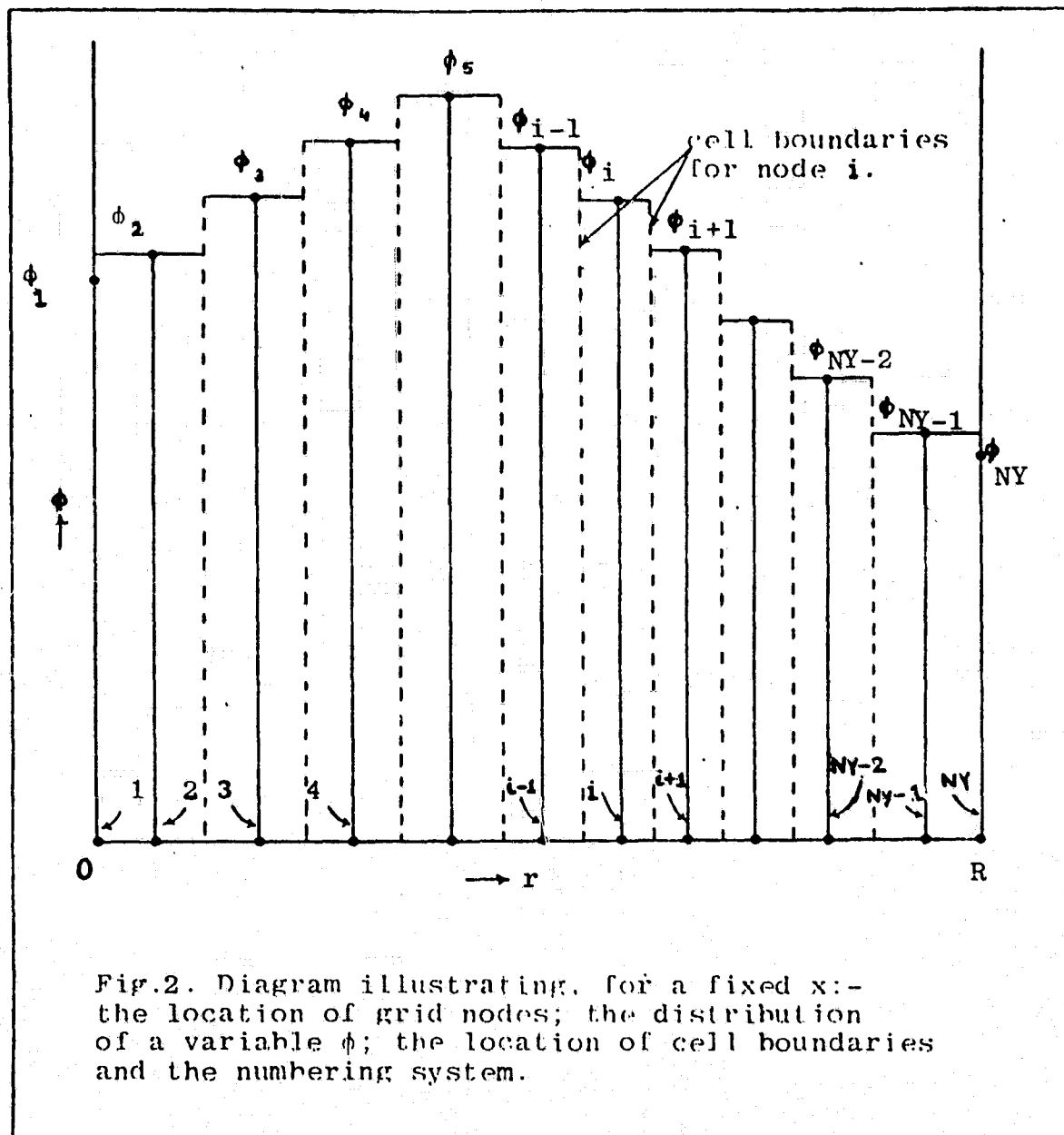


Fig.2. Diagram illustrating, for a fixed x :-
the location of grid nodes; the distribution
of a variable ϕ ; the location of cell boundaries
and the numbering system.

3.2.2 The longitudinal grid

The distribution of the longitudinal grid is similar to the cross-stream arrangement. The value of Δx , the increment in x between successive grid nodes, can be varied at will. As is usual in numerical work, small values of Δx (and also Δy) increase accuracy, but also computer time and storage. The right choice always represents a compromise.

3.3 The Finite-Difference Equations

3.3.1 Motive and method

A five-node finite-difference relation will now be derived connecting the value of a dependent variable ϕ_i at a node P with those of:- (a) its two neighbours at the same x -value, ϕ_{i+1} and ϕ_{i-1} ; (b) its two neighbours at the same r -value, ϕ_E and ϕ_W . This is to be a linear formula of the form:

$$D_i \phi_i = A_i \phi_{i+1} + B_i \phi_{i-1} + A_E \phi_E + A_W \phi_W + S_u \quad (46)^*$$

where A_W , A_E , etc., will be treated as constants, the expressions for which are derived by integration of the differential equation (10) over a control volume surrounding the node where ϕ_i prevails. There will be an equation like (46) with individual coefficients, for each grid point, other than those on the boundaries, and for each of the dependent variables, u , v , $\hat{h}$, m_{fu} , and f .

In equation (46), the ϕ value at the W (upstream) station can be regarded as known. The ϕ values at the E (downstream) station

* ϕ_i , ϕ_{i+1} , and ϕ_{i-1} are also alternatively referred to as ϕ_P , ϕ_N , and ϕ_S respectively; A_i and B_i as A_N and A_S respectively.

are regarded as temporarily known, either from the results of a previous iteration, or from an initial 'guess' or estimate. It is therefore useful to combine the last three terms on the right-hand side into one, thus:

$$C_i = A_E \phi_E + A_W \phi_W + S_u \quad (47)$$

The result is an equation which focusses all the attention on the unknown ϕ 's namely:

$$D_i \phi_i = A_i \phi_{i+1} + B_i \phi_{i-1} + C_i \quad (48)$$

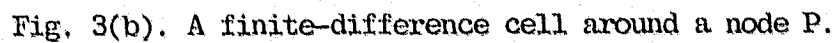
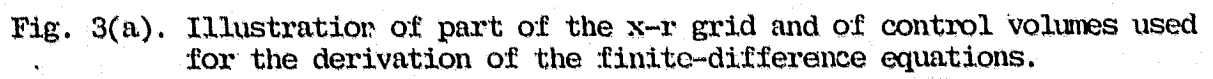
It is now necessary to obtain expressions from which A_i , B_i , C_i and D_i can be evaluated, by integrating the differential equation for ϕ over an appropriate control volume.

3.3.2 Integration over a control volume

Now the integration of the differential equation for ϕ , namely equation (10), over a control volume will be considered. Fig.3(a) illustrates the control volume and its neighbouring ones which must be considered. First, some general remarks are made about the locations of the control volume faces. The two control volumes near the boundaries differ from all the others in that, if the lower edge is denoted by $i-\frac{1}{2}$ and the upper by $i+\frac{1}{2}$:

$$\text{for } i = 2 \quad : \quad r_{i-\frac{1}{2}} = 0; \quad \text{for } i = NY-1 \quad : \quad r_{i+\frac{1}{2}} = R \quad (49)$$

whereas for all the other control-volume boundaries the appropriate formulae are:



$$r_{i-\frac{1}{2}} = \frac{1}{2} (r_{i-1} + r_i); \quad r_{i+\frac{1}{2}} = \frac{1}{2} (r_i + r_{i+1}) \quad (50)$$

Similar definitions apply to the grid in the x-direction:

$$\text{for } j=2: x_{j-\frac{1}{2}} = 0; \text{ for } j = NX-1: x_{j+\frac{1}{2}} = X \quad (51)$$

where X is the total x-dimension of the integration domain, whereas for all the other control-volume boundaries the appropriate formulae are:

$$x_{j-\frac{1}{2}} = \frac{1}{2} (x_{j-1} + x_j); \quad x_{j+\frac{1}{2}} = \frac{1}{2} (x_j + x_{j+1}) \quad (52)$$

With these definitions, it follows that the sum of all the control-volume "heights" and "lengths" equals that of the whole grid; thus:

$$\sum_{i=2}^{NY-1} (r_{i+\frac{1}{2}} - r_{i-\frac{1}{2}}) = R; \quad \sum_{j=2}^{NX-1} (x_{j+\frac{1}{2}} - x_{j-\frac{1}{2}}) = X \quad (53)$$

Thus, if conservation is satisfied for each of the individual control volumes, it will surely also be satisfied for the flow domain.

It is now necessary to apply the ϕ -profile assumption of Fig. 2 and to introduce further assumptions permitting evaluation of the gradients and other terms in equation (10) so as to arrive at expressions for A_i , B_i , C_i and D_i of equation (48).

(a) Diffusion and convection terms

The west face of the cell with area a_w , Fig. 3(b), is first considered. The finite-difference expression for the diffusion flux $J_{\text{diff},\phi,w}$ is given by:

$$a_w J_{\text{diff},\phi,w} = - a_w \Gamma_{\phi,w} (\phi_P - \phi_W) / \delta_w \quad (54)$$

where

$$\Gamma_{\phi,w} = \frac{1}{2} (\Gamma_{\phi,W} + \Gamma_{\phi,P}) \quad (55)$$

The finite-difference expression for the convection flux

$J_{\text{conv},\phi,w}$ is given by:

$$a_w J_{\text{conv},\phi,w} = u_w a_w \phi_w \rho_w \quad (56)$$

where

$$\left. \begin{aligned} \phi_w \rho_w &= \phi_W \rho_W \text{ for } a_w u_w > 0 \\ &= \phi_P \rho_P \text{ for } a_w u_w < 0 \end{aligned} \right\} \quad (57)$$

Expressions (57) are the consequence of the use of an upwind-differencing scheme for the convection terms.

By combining the diffusion and convection fluxes, the total flux through the west cell face, $J_{\text{tot},\phi,w}$ is obtained as:

$$\text{For } C_w > 0 : a_w J_{\text{tot},\phi,w} = (D_w + C_w) \phi_W - D_w \phi_P \quad (58)$$

$$\text{For } C_w < 0 : a_w J_{\text{tot},\phi,w} = D_w \phi_W - (D_w - C_w) \phi_P \quad (59)$$

In the above expressions:

$$D_w \equiv \Gamma_{\phi,w} a_w / \delta_w \quad (60)$$

$$C_w \equiv u_w a_w \rho_w \quad (61)$$

$$\begin{aligned} \text{and } \rho_w &\equiv \rho_W \text{ for } C_w > 0 \\ &\equiv \rho_P \text{ for } C_w < 0 \end{aligned} \quad (62)$$

Similarly, for the east cell-face:

$$\text{For } C_e > 0 : a_e J_{\text{tot}, \phi, e} = - D_e \phi_E + (D_e + C_e) \phi_P \quad (63)$$

$$\text{For } C_e < 0 : a_e J_{\text{tot}, \phi, e} = - (D_e - C_e) \phi_E + D_e \phi_P \quad (64)$$

In the above:

$$D_e \equiv \Gamma_{\phi, e} a_e / \delta_e \quad (65)$$

$$C_e \equiv u_e a_e \rho_e \quad (66)$$

$$\left. \begin{aligned} \text{and } \rho_e &\equiv \rho_E \text{ for } C_e < 0 \\ &\equiv \rho_P \text{ for } C_e > 0 \end{aligned} \right\} \quad (67)$$

Corresponding expressions for the total fluxes may be devised for the north and south cell faces.

$$\text{Let: } A_W \equiv \left| \begin{array}{l} \text{coefficient of } \phi_W \text{ in the} \\ \text{expression for } a_w J_{\text{tot}, \phi, w} \end{array} \right|$$

$$A_E \equiv \left| \begin{array}{l} \text{coefficient of } \phi_E \text{ in the} \\ \text{expression for } a_e J_{\text{tot}, \phi, e} \end{array} \right| ; \text{ etc.}$$

In terms of the D's and C's, these can be conveniently expressed as:

$$A_W = \max (D_W, D_W + C_W) \quad (68)$$

$$A_E = \max (D_e, D_e - C_e) , \text{ etc.} \quad (69)$$

where $\max (A,B)$ denotes the larger of A and B.

Then, the volume integral of the LHS of equation (10) may be written as:

$$\begin{aligned}
 & \iiint_{\text{vol}} (\text{LHS of 10}) dV \\
 &= - a_w J_{\text{tot},\phi,w} + a_e J_{\text{tot},\phi,e} - a_s J_{\text{tot},\phi,s} \\
 &\quad + a_n J_{\text{tot},\phi,n} \\
 &= \sum_i (A_i \phi_P - A_i \phi_i) - \{C_w - C_e - C_n + C_s\} \tag{70}
 \end{aligned}$$

where $\sum$ stands for the summation over the four nodes N, E, W and S.

Now, the terms in the curly brackets represent the net mass flow into the cell and should be zero by continuity. Therefore the following equation may be written:

$$\begin{aligned}
 & \iiint_{\text{vol}} (\text{LHS of 10}) dV \\
 &= \phi_P \sum_i A_i - \sum_i A_i \phi_i \tag{71}
 \end{aligned}$$

(b) The source term

In general the source term in equation (10) is not zero. Moreover, its composition may vary enormously with different ϕ 's and for best results different practices may need to be used for the evaluation of the integral of the source term over the cell volume. Therefore, generally it is assumed that the volume integral can be split into two terms as:

$$\iiint_{\text{vol}} S_{\phi} dV = S_u + S_p \phi_p \quad (72)$$

where S_u and S_p are two functions whose composition depends on the particular ϕ considered. If there is no dependence of the integral on ϕ_p , S_p can be put equal to zero.

There are many occasions where it is possible to have several different arrangements for the two functions S_u and S_p . In these cases, a simple rule is to choose an arrangement which gives a negative value to S_p ; this helps to promote numerical stability. When the particular ϕ under consideration is known to assume positive values only (e.g. species concentrations), one should in addition try to ensure that S_u is always positive.

(c) Final form of the finite-difference equation

Equating expressions (71) and (72) gives the finite-difference equation for ϕ_p as:

$$\phi_p = \frac{A_W \phi_W + A_E \phi_E + A_N \phi_N + A_S \phi_S + S_u}{(A_W + A_E + A_N + A_S) - S_p} \quad (73)$$

In the above equation the A's are given by:

$$A_W = \max (D_w, D_w + C_w) \quad (74)$$

$$A_E = \max (D_e, D_e - C_e) \quad (75)$$

$$A_N = \max (D_n, D_n - C_n) \quad (76)$$

$$A_S = \max (D_s, D_s + C_s) \quad (77)$$

The D's and C's in the above equations are given by:

$$D_w \equiv \frac{1}{2} (\Gamma_{\phi, W} + \Gamma_{\phi, P}) a_w / \delta_w \quad (78)$$

$$D_e \equiv \frac{1}{2} (\Gamma_{\phi, E} + \Gamma_{\phi, P}) a_e / \delta_e \quad (79)$$

$$D_n \equiv \frac{1}{2} (\Gamma_{\phi, N} + \Gamma_{\phi, P}) a_n / \delta_n \quad (80)$$

$$D_s \equiv \frac{1}{2} (\Gamma_{\phi, S} + \Gamma_{\phi, P}) a_s / \delta_s \quad (81)$$

$$C_w \equiv a_w u_w \rho_w \quad (82)$$

$$C_e \equiv a_e u_e \rho_e \quad (83)$$

$$C_n \equiv a_n v_n \rho_n \quad (84)$$

$$C_s \equiv a_s v_s \rho_s \quad (85)$$

It is worth remarking that the A's are always positive; this has been ensured by the use of upwind differencing in the convection terms.

Later it will be shown that staggered locations for the velocities will be used. In accordance with this, velocities are actually stored at locations marked by arrows in Fig. 3; in this case the velocities will be referred to by capital subscript according to the following:

$$u_e \equiv u_P ; u_w = u_W ; v_n \equiv v_P \text{ and } v_s \equiv v_S$$

The u-velocities are stored on the east face of the continuity cell and v-velocities on the north face of the cell.

3.3.3 The momentum equations

The finite-difference momentum equations have the same final form as that for the general ϕ equation, viz. equation (73). However, in the derivation of the equation, two differences in practice may be identified. Firstly, different finite-difference cells are used. This arises because of the adoption of staggered storage locations for the velocity components. Thus, the finite-difference equation for u is derived by integrating the x -momentum equation over the cell shown in Fig. 4(a). This cell is formed by two adjacent constant x -grid lines and two lines drawn mid-way between adjacent constant- r grid lines. A different but similarly constructed cell is used for v , as shown in Fig. 4(b).

The second difference lies in the way the diffusion and convection terms (i.e. D_e , D_w , C_e , C_w) through the cell faces are evaluated. These terms, for a velocity cell, are all obtained from those for the ϕ cells which overlap the particular velocity cell in question. Thus, the term, diffusion or convection, through the west face of the u cell, Fig. 4(a), is obtained as the arithmetic mean of the corresponding fluxes through the west and east faces of the continuity cell enclosing the node P , i.e. for a u cell (Figure 4(a)),

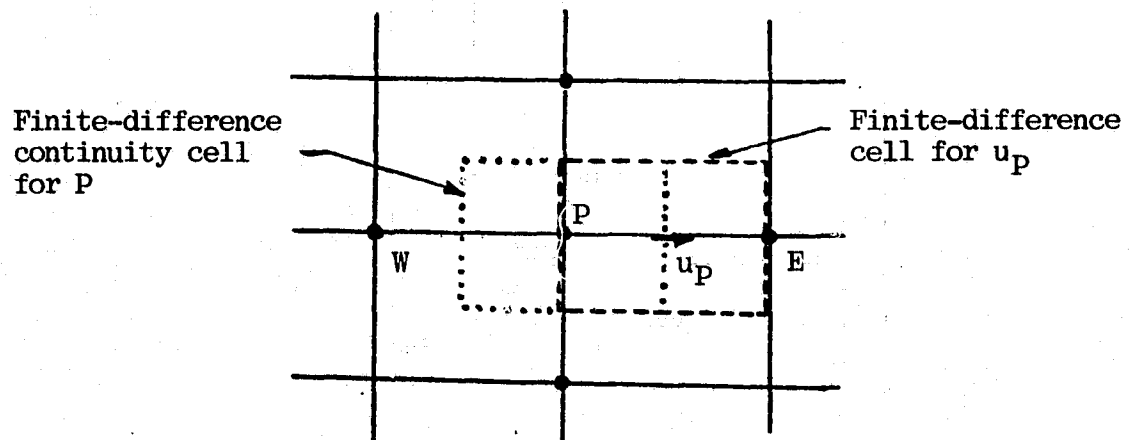
$$A_w = \max \left\{ \frac{1}{2}(D_e + D_w), \frac{1}{2}(D_e + D_w) - \frac{1}{2}(C_e + C_w) \right\} \quad (86)$$

$$A_E = \max \left\{ \frac{1}{2}(D_{ee} + D_e), \frac{1}{2}(D_{ee} + D_e) - \frac{1}{2}(C_{ee} + C_e) \right\} \quad (87)$$

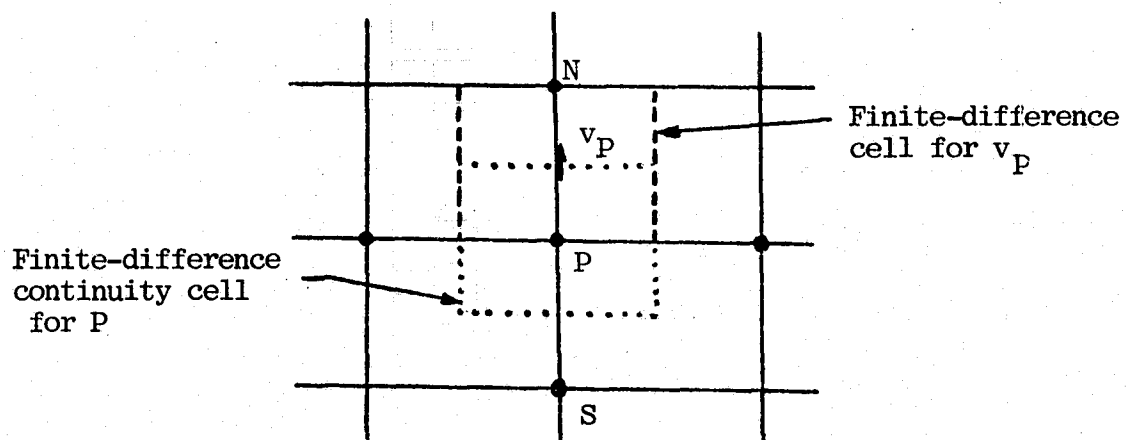
C_{ee} = convection flux through the east face of the continuity cell surrounding node E (Fig. 4(a)).

D_{ee} = diffusion flux through the east face of the continuity cell surrounding node E (Fig. 4(a)).

Exactly similar procedures are adopted for the other cell faces and for the v -cells. This practice offers two main advantages: computational simplicity, and, more consistent satisfaction of the conservation principle for the different types of cells.



(a) A u-cell



(b) A v-cell

Fig. 4: Diagrams illustrating the finite-difference cells for the component velocities.

3.3.4 The pressure-correction equation

A special practice is adopted for the solution of the continuity equation. The sequence is as follows:

- (i) Using an estimated (or previous iteration) pressure field p^* , the x- and r-momentum finite-difference equations are solved. This gives a first approximation to the velocity field (designated the 'starred' velocity field, u^* and v^*). This field in general does not satisfy the continuity equation.
- (ii) Correction u' , v' and p' to the starred velocity field (u^* , v^*) and the estimated pressure field p^* are derived from the continuity equation. These corrections are added to the starred fields:

$$u = u^* + u' \quad (88)$$

$$v = v^* + v' \quad (89)$$

$$p = p^* + p' \quad (90)$$

This results in a velocity field which is in local continuity balance.

- (iii) In addition to the above steps, block adjustment techniques are used at intermediate stages (see Sec. 3.8) in order to obtain integral mass and momentum balances.

The derivation of the equations for the corrections u' , v' , and p' will now be considered.

Figure 3(b) shows a cell around the node P together with the velocities crossing its four faces. The velocity u_p is corrected for continuity using a correction u'_p which is assumed to result from changes of pressure at locations on both sides of it, i.e.

p'_P and p'_E , according to:

$$u'_P = \frac{\partial u_P}{\partial p_P} p'_P + \frac{\partial u_P}{\partial p_E} p'_E \quad (91)$$

Now, the finite-difference equation for u_P can be written as (general form being equation (73)):

$$(\sum_i A_i - S_P) u_P = \sum_i A_i u_i + \{a_e(p_P - p_E) + S'_u\} \quad (92)$$

where $\sum_i$ denotes the summation over the four neighbouring nodes N, E, W and S; the S_u component of the source term has been split into the terms inside the curly brackets to show the pressure-gradient term explicitly; and a_e is the area of the east cell-face. Assuming that all the coefficients in (92) are not affected by changes in the p 's:

$$u'_P = \left(\frac{a_e}{D_P}\right) (p'_P - p'_E) \quad (93)$$

$$\text{where } D_P = \sum_i A_i - S_P \quad (94)$$

Other velocity corrections can be derived similarly.

By requiring the satisfaction of continuity (i.e. equation (5) integrated over a ϕ cell),

$$\begin{aligned} a_e \rho_e (u_P^* + u'_P) - a_w \rho_w (u_W^* + u'_W) + a_n \rho_n (v_P^* + v'_P) - \\ - a_s \rho_s (v_S^* + v'_S) = 0 \end{aligned} \quad (95)$$

where ρ_w and ρ_e are as defined in equations (62) and (67); ρ_n and ρ_s are similarly defined.

By substituting velocity correction equations, such as (93), for u'_p , u'_w , v'_p and v'_s into equation (95) an equation for the pressure-correction p' is obtained. The equation will have the standard form, i.e.:

$$D'_p p'_p = \sum_i A_i p'_i + S_u \quad (96)$$

where $\sum_i$ denotes summation over the four neighbouring nodes.

Thus the above equation can be solved by the same techniques as used for all the other finite-difference equations.

3.3.5 Section-wise momentum balance

During the solution of the momentum and continuity equations, section-wise momentum balances are performed in order to procure integral conservation of momentum across the strip of finite-difference cells currently being solved for. The procedure is termed as SNIP i.e. Start the momentum equations with a New Integration for Pressure, since it provides a starting guess of the pressure field (i.e. the p^* field of Sec. 3.3.4) for the solution of the momentum equations.

The procedure consists in adding up all the terms of the x-momentum finite-difference equation along a line of constant x and making this sum zero by block adjustment of pressure. The formula for the adjustment of pressure is obtained from the x-momentum finite-difference equation (92) as:

$$\Delta \bar{p} = - \frac{\sum_j \left[\sum_i (A_i - S_p) u_p - \sum_i A_i u_i - S_u \right]}{\text{(Total area of strip normal to the x-direction)}} \quad (97)$$

where $\sum_j$ denotes the summation over all cells at the x-location under consideration and $\sum_i$ denotes the summation over the four

neighbouring nodes.

It should be noted that $\Delta \bar{p}$ is added to all pressures downstream of the column of cells under consideration. An option is provided for the user to switch the above procedure off by setting the index ISNIP=1.

3.4 Solution of the finite-difference equations

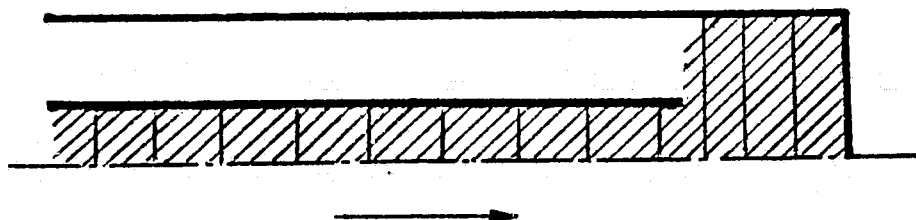
3.4.1 Solution procedure

The numerical procedure used to solve the finite-difference equations is an iterative one, requiring the flow field to be swept repeatedly until termination, either through having satisfied the convergence test, or through some other control.

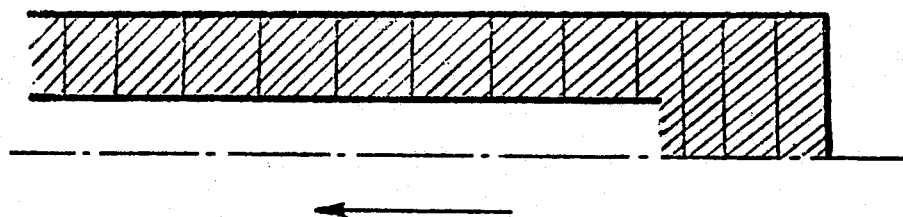
In a sweep of the field, strips of finite-difference cells along constant-x grid lines are considered, one by one; hence the procedure progresses line-by-line. The extent of the field covered during forward and reverse marches is shown in Fig. 5. At each line, all the dependent variables are considered, one after another, and, for each variable, finite-difference equations are set up, one for each of the cells on the line, Fig. 6. These finite-difference equations are solved before the next variable is considered. Thus, the equation set, dealt with each time, consists of the finite-difference equations for all the cells along a grid line. Since all the finite-difference equations have the same general form of (73), the equation for one of the variables ϕ can be written as:

$$\phi_i (\sum_j A_{ij} - S_{pj}) = \sum_j A_{ij} \phi_j + S_{uj} \quad (98)$$

In the above equation the subscript j refers to the cell on the jth constant -r grid line ; ϕ_j is normally calculated for all the control cells in the line viz. from, j=2, to j=N-1. The values for j equal to 1 and N are the boundary values, which must be specified, while the other values ϕ on the line are



(a) Forward March



(b) Reverse March

Fig. 5: The extent of the field covered by the cross-stream TDMA during forward and reverse marches.

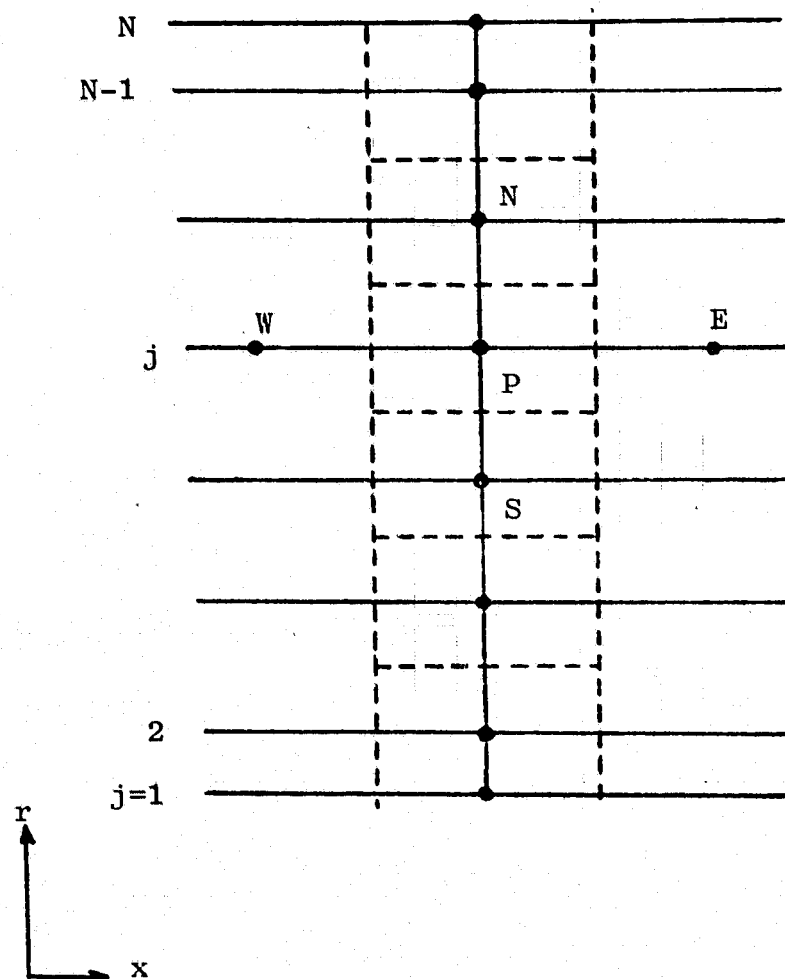


Fig. 6: Diagram illustrating a typical strip of cells along a constant- x grid line.

calculated. Symbol $\sum_i$ denotes the sum over the four neighbour nodes of j .

The above set of equations (98) which has to be solved for the unknown ϕ 's is of a form which enables the solution to be obtained using the well-known tri-diagonal matrix algorithm (TDMA). Details of this method may be found, for example in Ref. 1.

3.4.2 Under-relaxation

The solution procedure described above involves the solution of the finite-difference equations which are expressed in a linearised form. However the equations are not truly linear; therefore, an iterative solution procedure is required to continually update the coefficients until a converged solution is obtained. If the changes in the values of the variables from one iteration to the next are large, there is a possibility that convergence may not be achieved at all. To keep these changes sufficiently small, the dependent variables are suitably under-relaxed. Two forms of under-relaxation are described below.

(a) Inertial under-relaxation

The central idea in inertial under-relaxation is to under-relax the variables selectively at those locations where the source term in the equation is large compared to the convection and diffusion terms. At such locations, changes in the source term produce large changes in the variable, which may then result in divergence. Inertial under-relaxation limits the changes in the variable by imposing a gradual change in the source term. This is achieved by adding a term $a(\phi^O - \phi_P)$ to the source term, where ϕ^O is the previous iteration value of ϕ_P and 'a' is a constant. The additional term has the opposite sign of the changes to the source term; and it therefore diminishes the extent to which the source term is changed.

When convergence is achieved $\phi^0 \rightarrow \phi_p$, the additional term tends to zero; and therefore the solution obtained is the solution of the original equation. The calculation of the constant 'a' will now be described.

Consider, for example, that the changes in ϕ between successive iterations should be restricted to 5 per cent,

$$\text{i.e.} \quad \left| \frac{\phi_p - \phi^0}{\phi^0} \right| = 0.05 \quad (99)$$

For small $\sum_i A_i \phi_i$ the finite-difference equation (73) for ϕ_p can be approximated by:

$$(\sum_i A_i - S_p) \phi_p \approx S_u \quad (100)$$

If S_u^0 is the previous iteration value of S_u corresponding to ϕ^0 , and assuming $(\sum_i A_i - S_p)$ to remain approximately constant,

$$(\sum_i A_i - S_p) (\phi_p - \phi^0) \approx S_u - S_u^0 \quad (101)$$

The additional term $a(\phi^0 - \phi_p)$ is added to the right-hand side of this equation giving:

$$(\sum_i A_i - S_p) (\phi_p - \phi^0) \approx (S_u - S_u^0) + a(\phi^0 - \phi_p) \quad (102)$$

Therefore, from equations (99) and (102),

$$a + (\sum_i A_i - S_p) \approx 20 \left(\frac{S_u - S_u^0}{\phi^0} \right) \quad (103)$$

Since $(\sum_i A_i - S_p)$ is usually small compared to a ,

$$a \approx \frac{20 (S_u - S_u^0)}{\phi^0} \quad (104)$$

This value of 'a' will limit changes in ϕ_p to 5 per cent. When oscillations or divergence are being observed, it is necessary to increase the value of 'a'. However, care is to be taken to see that the solution is not 'frozen' by excessive under-relaxing.

In the present work inertial under-relaxation is employed only for the u- and v-velocities, since experience has shown that it is not necessary to under-relax the other variables.

(b) Use of an under-relaxation factor

The second method of under-relaxation is to consider the value of ϕ to be a weighted mean of its current-iteration and previous-iteration values.

This method is employed only for pressure and amounts to modifying equation (90) as:

$$p = p^* + \alpha_p p' \quad (105)$$

where α_p the under-relaxation factor lies between 0 and 1.

3.5 Solution of the Chemical-Equilibrium Equations

3.5.1 Solution procedure

The chemical-equilibrium equations were discussed in Section 2.6. They are solved by the procedure given in Ref. 2. The salient features of this technique are described next.

The Newton-Raphson iteration method is used to solve the equilibrium equations. The correction variables are (NLM + 2) in number, where NLM is the number of distinct elements in the system being considered (there are three in the present case, i.e. C, O, and H). The corresponding correction equations are obtained after appropriate linearization as follows.

- (a) The correction equations for the conservation of elements are expressed in terms of the non-dimensionalized Lagrange multipliers, π_i as:

$$\begin{aligned} \sum_{i=1}^{NLM} \left(\sum_{k=1}^{NSE} a_{ik}^L a_{jk}^L \sigma_k \right) \pi_i + \left(\sum_{k=1}^{NSE} a_{jk}^L \sigma_k \right) \Delta \log \sigma_m \\ + \left\{ \sum_{k=1}^{NSE} a_{jk}^L \sigma_k \left(\frac{h_k}{RT} \right) \right\} \Delta \log T = \sum_{k=1}^{NSE} a_{jk}^L \sigma_k \left(\frac{g_k}{RT} \right), \quad j=1, NLM \end{aligned} \quad (106)$$

- (b) The correction equation for the reciprocal of the mixture molecular weight, σ_m is:

$$\begin{aligned} \sum_{i=1}^{NLM} \left\{ \sum_{k=1}^{NSE} a_{ik}^L \sigma_k \right\} \pi_i + \left\{ \sum_{k=1}^{NSE} \sigma_k - \sigma_m \right\} \Delta \log \sigma_m \\ + \left\{ \sum_{k=1}^{NSE} \sigma_k \left(\frac{h_k}{RT} \right) \right\} \Delta \log T = \sigma_m - \sum_{k=1}^{NSE} \sigma_k + \sum_{k=1}^{NSE} \sigma_k \left(\frac{g_k}{RT} \right) \end{aligned} \quad (107)$$

- (c) The correction equation for temperature is based on an enthalpy balance condition (i.e., enthalpy of the products is specified) and is:

$$\sum_{i=1}^{NLM} \left\{ \sum_{k=1}^{NSE} a_{ik}^L \sigma_k \left(\frac{h_k}{RT} \right) \right\} \pi_i + \left\{ \sum_{k=1}^{NSE} \sigma_k \left(\frac{h_k}{RT} \right) \right\} \Delta \log \sigma_m$$

$$\begin{aligned}
& + \left\{ \sum_{k=1}^{\text{NSE}} \sigma_k \left(\frac{C_{pk}}{R} \right) + \sum_{k=1}^{\text{NSE}} \sigma_k \left(\frac{h_k}{RT} \right)^2 \right\} \Delta \log T \\
& = \frac{h_{pr}}{RT} - \sum_{k=1}^{\text{NSE}} \sigma_k \left(\frac{h_k}{RT} \right) + \sum_{k=1}^{\text{NSE}} \sigma_k \left(\frac{h_k}{RT} \right) \left(\frac{g_k}{RT} \right)
\end{aligned} \tag{108}$$

where h_{pr} is the enthalpy (sensible & chemical) of the equilibrium-products and is obtained from equation (32).

The correction equations (106), (107), (108) involve the unknowns π_i ($i=1, \text{NLM}$), $\Delta \log \sigma_m$, and $\Delta \log T$. They are solved by a standard Gaussian elimination procedure. The correction matrix will become singular at the solution point when the coefficient of $\Delta \log \sigma_m$ in equation (107) is identically zero. This potential singularity is avoided by a single interchange between the row involving the zero coefficient of $\Delta \log \sigma_m$ and any other row (in practice, the row with the largest coefficient of $\Delta \log \sigma_m$ is selected.) All other diagonal elements are positive and do not require special treatment.

The new values of the variables are then obtained as:

$$\Delta \log \sigma_k = \left(\frac{h_k}{RT} \right) \Delta \log T - \left(\frac{g_k}{RT} \right) + \Delta \log \sigma_m + \sum_{i=1}^{\text{NLM}} a_{ik}^L \pi_i, \quad k=1, \text{NSE} \tag{110}$$

$$\log \sigma_i^{(k+1)} = \log \sigma_i^{(k)} + \eta (\Delta \log \sigma_i)^{(k)}, \quad i=1, \text{NSE} \tag{111}$$

$$\log \sigma_m^{(k+1)} = \log \sigma_m^{(k)} + \eta (\Delta \log \sigma_m)^{(k)} \tag{112}$$

$$\log T^{(k+1)} = \log T^{(k)} + \eta (\Delta \log T)^{(k)} \tag{113}$$

where the superscripts indicate the iteration number, and η is an under-relaxation parameter ($0 < \eta \leq 1$). The determination of η and the convergence criterion are discussed in Section 3.5.3.

3.5.2 Initial estimate of species mole-numbers and temperature

The initial estimate of the species mole-numbers is based on complete stoichiometric combustion. Thus if x and y are the number of kg-atoms of carbon and hydrogen respectively, per kg of mixture, the initial estimate is given by:

$$\sigma_{\text{CO}_2} = x \quad (114)$$

$$\sigma_{\text{H}_2\text{O}} = y/2 \quad (115)$$

All other mole numbers are set equal to a small number 10^{-6} .

The initial estimate for temperature is obtained from an adiabatic enthalpy balance for the assumed composition and the given mixture enthalpy. The procedure is the same as that described in Section 3.7.

3.5.3 Under-relaxation and convergence criterion

The self-adjusting under-relaxation parameter η similar to that of Ref. 2 is used here. This parameter is determined at each iteration from:

$$\eta = \text{minimum of } (1, \eta_1, \eta_2) \quad (116)$$

where η_1 and η_2 are quantities which are defined below.

- (a) For T , σ_m , and species with $(\sigma_i/\sigma_m) > 10^{-8}$ and $\Delta \log \sigma_i > 0$, η_1 is defined as:

$$\eta_1 \equiv \frac{0.2}{\max(|\Delta \log T|, |\Delta \log \sigma_m|, |\Delta \log \sigma_i|)} \quad (117)$$

This causes the correction of the variables T , σ_m , and σ_i to be scaled so that none of the variables is increased by more than a factor of 1.22 ($=\exp(0.2)$) on any one iteration. This is different from the definition of η_1 in Ref 2, which permits maximum increases by a factor of up to 7.39 ($=\exp(2)$) on any one iteration.

- (b) For species with $(\sigma_i/\sigma_m) < 10^{-8}$ and $\Delta \log \sigma_i > 0$, η_2 is defined as:

$$\eta_2 \equiv \left| \frac{\log(10^{-4}) - \log(\sigma_i/\sigma_m)}{\Delta \log \sigma_i - \Delta \log \sigma_m} \right| \quad (118)$$

This scales all the corrections so that the species with σ_i initially less than 10^{-8} increase to no more than 10^{-4} .

A convergence criterion similar to that recommended in Ref. 2. is used. This is:

$$\left(\frac{\sigma_i}{\sigma_m} \right) |\Delta \log \sigma_i| \leq 1.0 \times 10^{-10}, \quad i=1, \text{ NSE} \quad (119)$$

and

$$|\Delta \log \sigma_m| \leq 1.0 \times 10^{-10} \quad (120)$$

3.5.4 Polynomial fits for equilibrium-product-species concentrations

The equilibrium compositions are represented in terms of polynomials of enthalpy at different pressures. The polynomial coefficients are determined in computations external and prior to the main computer code. The steps for obtaining these polynomials are now described.

The equilibrium compositions are computed by the method of Section 3.5.1 for several values of enthalpy at different pressures. At a given pressure, the logarithm of the equilibrium-species mass fraction is represented as a polynomial of enthalpy. There are two distinct polynomials (one over each of two ranges of enthalpy), both of third order, for each of the species. The logarithm of the species mass fraction is used since the variation in mass fraction over the enthalpy range is a few orders of magnitude (for species like O, H, OH etc.). In the main code, when the equilibrium composition is required for a particular enthalpy and pressure the polynomials are used to calculate the species mass fractions.

3.6 Solution of the Chemical-Kinetics Equations

3.6.1 Solution procedure

The chemical-kinetics equations were discussed in Section 2.7. They are solved by the procedure described in Ref. 3; it will be only briefly described here.

The procedure involves a point-by-point simultaneous solution of all the pollutant concentrations (i.e. N, NO, NO₂, and N₂O). The line-by-line procedure which is used to solve for other dependent variables (u , v , $\hat{h}$, f , and m_{fu}) is not suitable for the solution of the chemical-kinetics equations. The reason is that

the concentration of any pollutant species at a point depends more strongly on the concentrations of the other pollutant species at the same point rather than its own concentration at neighbouring points. The line-by-line procedure would, under such conditions, require an excessively large number of iterations to achieve convergence (e.g. Ref.3).

The Newton-Raphson method is used to solve the chemical-kinetics equations. The correction equations for the species mole numbers are expressed, after appropriate linearization as:

$$\sum_{k=1}^{NSK} \{A_p \sigma_i \delta_{ik} + \sum_{j=1}^M (\alpha'_{ij} - \alpha''_{ij})(R_j \alpha'_{kj} - R_{-j} \alpha''_{kj}) \Delta \log \sigma_k\} \\ = A_p(\sigma_i^* - \sigma_i) - \sum_{j=1}^M (\alpha'_{ij} - \alpha''_{ij})(R_j - R_{-j}), \quad i=1, NSK \quad (121)$$

Equations (121) involve the unknowns $\Delta \log \sigma_k$ ($k=1, NSK$). The equations are solved by a standard Gaussian elimination procedure. All the diagonal elements of the correction matrix are positive, so that no matrix conditioning is necessary.

The new values of the variables are then obtained as:

$$\log \sigma_i^{(k+1)} = \log \sigma_i^{(k)} + \eta (\Delta \log \sigma_i)^{(k)}, \quad i=1, NSK \quad (122)$$

where the subscripts indicate the iteration number and η is an under-relaxation parameter ($0 < \eta \leq 1$). The determination of η , and the convergence criterion, are discussed below.

3.6.2 Initial estimate of the mole numbers of pollutant species

The initial estimate is obtained by setting the concentrations of the pollutant species at any grid node equal to those at the corresponding upstream node. For the very first set of cross-stream points, the initial estimates of the concentrations are set to a small number, 10^{-15} to 10^{-20} . This procedure is followed when sweeping through the integration domain for the first time. For subsequent sweeps, the values at the particular grid node from the previous sweep are used as the initial estimates for the solution of the correction equation (121).

3.6.3 Under-relaxation and convergence criterion

The self-adjusting under-relaxation parameter of Ref. 2 is used without modification (see also Section 3.5.3). The solution at any grid node is assumed to have converged when the concentrations of the NO_x -species remain within a certain value from one iteration to the next.

3.7 Solution of the Auxiliary Equations

The auxiliary equations were discussed in Section 2.5. Of these only the equations dealing with the temperature of the mixture require an iterative solution procedure; the other equations involve straightforward algebraic expressions. All heat transfer effects affect the enthalpy equation which in turn affects the fluid temperature according to equation (146) of Section 5.2.

The temperature equation (26) is solved by the Newton-Raphson iteration method. The Newton-Raphson correction equation for temperature is:

$$h - \sum_{j=1}^{NS} m_j h_j (T_k) = \left(\sum_{j=1}^{NS} C_{pj} (T_k) m_j \right) \Delta T_k \quad (123)$$

$$T_{k+1} = T_k + \Delta T_k \quad (124)$$

where $T_k \equiv$ the temperature at the k^{th} iteration

$h_j(T_k) \equiv$ the enthalpy of species j at temperature T_k

$C_{pj}(T_k) \equiv$ the constant pressure specific heat of species j at temperature T_k (see Section 5.2).

Convergence is monitored by computing $|\Delta T_k / T_{k+1}|$ at each iteration; and, when its value falls below a prespecified limit, the iteration is terminated.

3.8 Summary of the solution procedure

Now that the main features of the finite-difference solution procedure have been described, it will be useful to summarize the main steps involved:

- (1) At the start u_1 's and ϕ_0 's are known (Fig.7); if this strip of cells is at the boundary the u_1 's and ϕ_0 's are known from the boundary conditions; otherwise they are known from the solution at the previous strip. The p_2 's are 'guessed' (see step 8). The problem is then to determine u_3 's, v_2 's, p_2 's, and ϕ_2 's.
- (2) The u_3 's are guessed so as to satisfy overall continuity for the strip. The p_4 's are then estimated (based on the guessed p_2 's) so that overall momentum is satisfied for the strip, with assumed u_3 's.
- (3) The x-momentum finite-difference equation is solved for u_3 's.

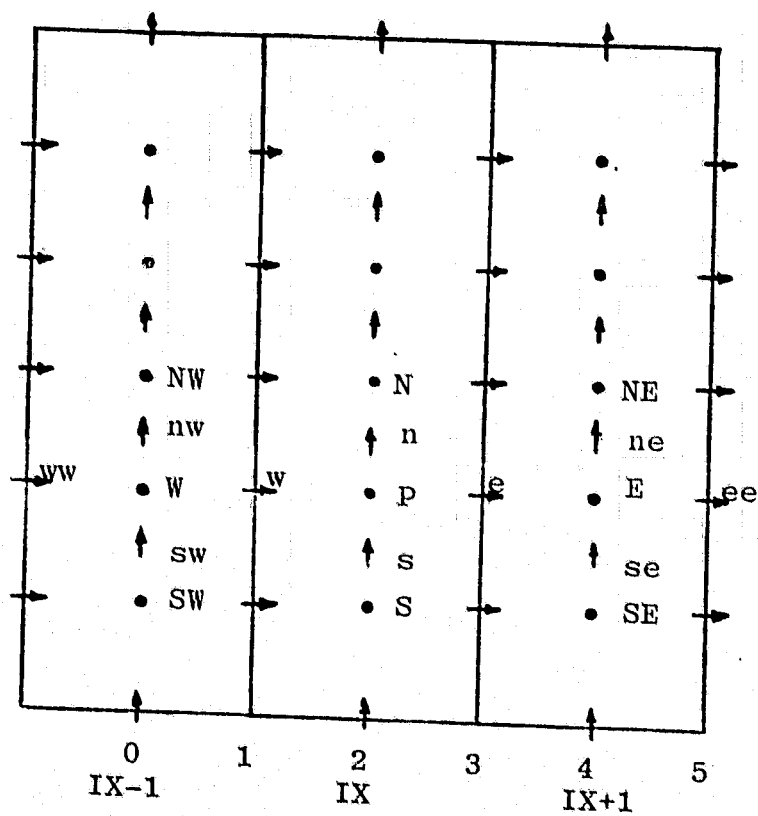


Fig. 7: Diagram illustrating the solution sequence.

- (4) Overall continuity is checked at Section 3 and the u_3 's obtained in Step (3) are all adjusted by a uniform amount to satisfy overall continuity.
- (5) The r-momentum finite-difference equation is solved for v_2 's.
- (6) The finite-difference equations for all other variables ϕ are solved to obtain the ϕ_2 's.
- (7) Continuity imbalances for individual cells at 2 are checked and the pressure-correction equation is solved; corresponding adjustments are then made to u_3 's, v_2 's and p_2 's. This results in u_1 's, v_2 's and u_3 's being in overall and local continuity balance.
- (8) Finally, the p_4 's are adjusted by a uniform amount (as in Step 2) to ensure overall momentum satisfaction for the strip. These p_4 's are used as the 'guessed' values for the solution at the next strip.
- (9) The solution then advances in the x-direction to the next strip. This continues until the whole flow domain has been swept.
- (10) These sweeps are repeated until convergence is achieved. Facility is also provided to repeat the solution at a given line (i.e. perform iterations at a line). These iterations are terminated when the residues in all the equations being solved fall below a prespecified small value; or when the number of iterations exceeds a prespecified maximum value.

4. FURTHER FEATURES OF THE CALCULATION PROCEDURE

4.1 The Treatment of Wall Boundaries

The wall boundaries are treated by including the wall shear stress in the equation for the velocity parallel to the wall; and by setting the velocity at the wall to zero (the no-slip condition). The treatment is similar to that employed in References 7 and 10.

The wall shear stress τ is given by:

$$\tau = s (\rho u^2)_{NW} \quad (125)$$

where the subscript NW refers to the near-wall node.

The quantity s is the shear-stress coefficient and is given by (Reference 7):

$$s^{\frac{1}{2}} = \frac{\kappa}{\ln (ERs^{\frac{1}{2}})} \quad (126)$$

where E = constant (taken to be 9.0);

κ = von Karman constant (taken to be 0.435);

R = Reynold's number = $(\rho u \Delta y / \mu_\ell)_{NW}$;

Δy = distance of wall from the near-wall node;

μ_ℓ = laminar viscosity.

The shear stress is incorporated into the finite-difference equations by linearization of the term ρu^2 as $\rho |u|u$. Details may be found in Reference 7. In order to solve eq. (126) for s , a value of s is guessed and substituted in the RHS of eq. (126) to give a better estimate of s . The process is repeated until the values of s from one step to the next remain within 0.01%.

4.2 The Treatment of the Inner Wall

The effect of the inner wall is introduced by modifying the source terms of the u-momentum equation at the nodes adjacent to the inner wall. The source-term modification is done to include the effects of the wall shear stress as per the discussion of Section 4.1.

4.3 The Treatment of Heat Transfer

4.3.1 Heat Transfer processes considered

In this section the inclusion of heat transfer effects into the solution procedure is described. These effects enter as boundary conditions in the stagnation enthalpy equation. The following modes of heat transfer are considered in the present work:

- (i) convective heat transfer from hot combustion gases to passage walls;
- (ii) convective heat transfer from hot walls to colder inlet fuel-air mixture;
- (iii) axial wall conduction;
- (iv) wall to wall radiation;
- (v) free and forced convection from outer wall to surroundings;
- (vi) radiation from outer wall to surroundings.

The radiant heat exchange between the flame and the walls is ignored since the methane-air flame has a low emissivity and since the mean beam length in the present case is small.

The inclusion of the heat transfer effects involves appropriate modifications of the source terms in the stagnation enthalpy equation at the inner and outer tube walls and at the end wall. These are described below.

4.3.2 Heat transfer at the inner tube wall

The heat transfer effects at the inner tube wall are introduced by modifying the source terms for the finite-difference cells at N, P, and S (Fig. 8) at the x-location currently being solved for. The various heat transfer processes are considered individually below.

(i) Heat transfer between wall and gases:

For heat transfer between N and P, the overall heat transfer coefficient $U_{1,0}$ is given by (Ref. 11):

$$\frac{1}{r_{1,0}U_{1,0}} = \frac{1}{r_{1,0}h_{1,0}} + \frac{\ln(r_{1,0}/r_P)}{k} \quad (127)$$

where k is the conductivity of the wall material (stainless steel) and $h_{1,0}$ is the convection heat transfer coefficient.

For heat transfer between S and P, the overall heat transfer coefficient $U_{1,i}$ is given by:

$$\frac{1}{r_{1,i}U_{1,i}} = \frac{1}{r_{1,i}h_{1,i}} + \frac{\ln(r_P/r_{1,i})}{k} \quad (128)$$

In the above equations, $h_{1,i}$ and $h_{1,0}$ are calculated from prescribed Stanton numbers $St_{1,i}$ and $St_{1,0}$:

$$h_{1,i} = St_{1,i} \rho_S |U_S| C_p \quad (129)$$

$$h_{1,0} = St_{1,0} \rho_N |U_N| C_p \quad (130)$$

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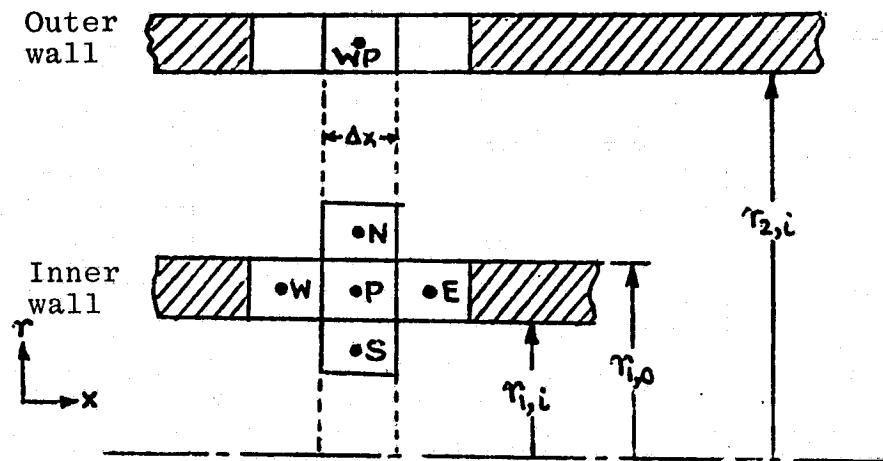


Fig. 8: Heat transfer calculation at inner tube wall.

where U_S and U_N are the velocities parallel to the wall at S and N respectively; and ρ is the density.

The values of the Stanton numbers in equations (129) and (130) are assumed to be 0.003, which in the authors' experience is typical of the flow situation being considered*.

The specific heat C_p appearing in the above equations is assumed to be constant ($=1100 \text{ J/Kg.}^\circ\text{K}$). It should be noted that it is possible to calculate C_p from the local values of temperature and composition, but in view of the other approximations involved, it is not worth going into this complication.

Finally, the heat fluxes are included in the finite-difference equations by augmenting the source terms of the enthalpy equation at nodes N, P, and S as:

$$Su_N = Su_N + U_{1,0}r_{1,0}\Delta x(T_P - T_N) \quad (131)$$

$$Su_P = Su_P + U_{1,0}r_{1,0}\Delta x(T_N) + U_{1,i}r_{1,i}\Delta x(T_S) \quad (132)$$

$$SP_P = SP_P - U_{1,0}r_{1,0}\Delta x - U_{1,i}r_{1,i}\Delta x \quad (133)$$

$$Su_S = Su_S + U_{1,i}r_{1,i}\Delta x(T_P - T_S) \quad (134)$$

(ii) Axial wall conduction

This is included in the finite-difference form of the enthalpy equation by modifying the source term at point P as:

$$Su_P = Su_P + \frac{k\Delta A}{\Delta x_1} (T_E - T_P) + \frac{k\Delta A}{\Delta x_2} (T_W - T_P) \quad (135)$$

* Since the writing of this report the program has been extended to compute the Stanton numbers locally. The corresponding update to the program is given in Appendix E.

where ΔA = east face area of the cell at P

$$\Delta x_1 = x_E - x_P \quad (136)$$

$$\Delta x_2 = x_P - x_W \quad (137)$$

Also, the east-west finite-difference coefficients (i.e. A_E and A_W of equation (73)) for node P are set to zero.

(iii) Wall to wall radiation

The treatment of Ref 11 for radiant heat exchange between two long, gray, coaxial cylinders is followed.

Therefore, the enthalpy-equation source term at P is modified as:

$$Su_P = Su_P + Q_{rad} \quad (138)$$

$$\text{where } Q_{rad} = \frac{\sigma(T_{WP}^4 - T_P^4)}{\frac{1}{A_P e_1} + \frac{1}{A_{WP}} \left(\frac{1}{e_2} - 1\right)} \quad (139)$$

σ = Stefan-Boltzmann constant ;

$$A_P = r_{1,0} \Delta x; \quad (140)$$

$$A_{WP} = r_{2,i} \Delta x; \quad (141)$$

T_{WP} = temperature of duct wall at same x-location as P;

$r_{2,i}$ = inner radius of duct wall;

e_1 = emissivity of inner duct wall material;

e_2 = emissivity of outer duct wall material.

4.3.3 Heat transfer at the outer tube wall

The heat transfer effects at the duct wall are introduced by modifying the enthalpy source terms at the nodes WP and WS (Fig. 9). The nodes WW, WP, and WE actually lie on the inner surface of the duct wall (these are the nodes corresponding to $i=NY$, Fig. 2); however, for the purpose of heat transfer calculations, the enthalpy and temperature associated with these nodes are

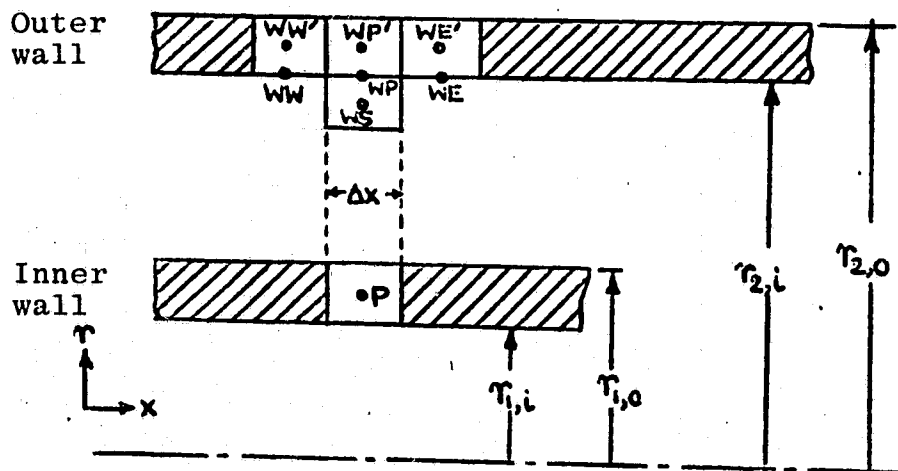


Fig. 9: Heat transfer calculation at the outer duct wall.

assumed to be the values at the middle of the duct wall (i.e. WE', WP', WW'). Also the TDMA solution for the enthalpy equation is extended to include WE', WP', WW' as internal nodes.

The various modes of heat transfer are summarised below:

(i) Heat transfer between wall and gases in the duct:

The method of treating this is identical to that discussed in Sec. 4.3.2(i) above. Again, the Stanton number is assumed to be 0.003.

(ii) Axial wall conduction

The method of treating axial wall conduction is identical to that discussed in Sec. 4.3.2(ii) above.

(iii) Wall to wall radiation

This has also been discussed in Sec 4.3.2(iii) above. Its inclusion involves modifying the enthalpy source term at WP' as:

$$Su_{WP'} = Su_{WP'} - Q_{rad} \quad (142)$$

where Q_{rad} is given by equation (139).

(iv) Free and forced convection from outer wall to surroundings

Since the flow is assumed to be axisymmetric, to consider free convection, the axis of the duct must be vertical; to consider forced convection, the axis of the duct must be parallel to the external free stream in which the duct is placed.

A brief study of the literature (e.g. Refs. 11, 12) shows that no simple correlations for calculating the free and forced convection for the above conditions exist. Most of the cases dealt with in

these references are for a cylinder with its axis normal to the free stream.

Therefore, in order to calculate the free and forced convection a prescribed Stanton number is assumed; again a value of 0.003 is assumed for lack of more accurate information. The inclusion of free and forced convection involves a modification of the enthalpy source at WP as:

$$Su_{WP} = Su_{WP} + St_{2,0} \rho |u_{\infty}| C_p (T_{surr} - T_{WP}) \quad (143)$$

where u_{∞} = the free stream velocity to which the duct is subjected;

T_{surr} = surroundings temperature.

(v) Radiation from outer wall to surroundings

This is included by modifying the enthalpy source term at WP as:

$$Su_{WP} = Su_{WP} + \sigma e (T_{surr}^4 - T_{WP}^4) \cdot \Delta x \cdot r_{2,0} \quad (144)$$

4.3.4 Heat transfer at the end wall

The end wall AB (Fig. 10) is treated similarly to the outer cylindrical wall AC. The TDMA solution is extended (for the enthalpy equation) to include the nodes in the wall AB. The only difference in the treatment of the wall AB (from the wall AC) is in the wall to wall radiation calculation; this does not exist since the wall AB is assumed not to exchange radiant energy with the other walls. This is consistent with the assumption made so far that the radiation leaving a wall is perpendicular to it. Instead the radiation to the surroundings will be from both surfaces of this wall and so has double the value given by the equation similar to (144).

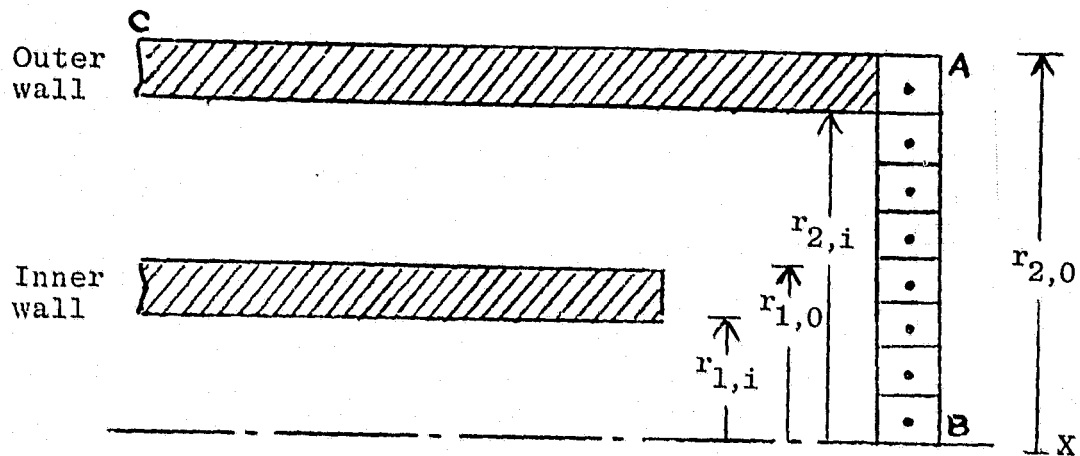


Fig. 10: Heat transfer calculation at end wall.

5. THERMODYNAMIC AND ELEMENT DATA

5.1 Element Data

The following information is required to describe the set of elements which make up the chemical species present in the system:

- the element symbol (e.g. C, O, H, and N);
- the corresponding atomic weight.

5.2 Thermodynamic Data

The thermodynamic data for constant pressure specific heat, enthalpy, and the entropy at one atmosphere for the chemical species are the same as those used in Ref. 2. These properties are expressed as polynomials in temperature.

$$\frac{C_p}{R} = Z_1 + Z_2 T + Z_3 T^2 + Z_4 T^3 + Z_5 T^4 \quad (145)$$

$$\frac{h}{RT} = Z_1 + \frac{Z_2 T}{2} + \frac{Z_3 T^2}{3} + \frac{Z_4 T^3}{4} + \frac{Z_5 T^4}{5} + \frac{Z_6}{T} \quad (146)$$

$$\frac{s^0}{R} = Z_1 \log T + Z_2 T + \frac{Z_3 T^2}{2} + \frac{Z_4 T^3}{3} + \frac{Z_5 T^4}{4} + Z_7 \quad (147)$$

There are thus seven coefficients $Z_1 \dots Z_7$ for each one of the chemical species for each one of two temperature ranges, 300°K to 1000°K , and 1000°K to 5000°K . The pressure effects on the thermodynamic data were not taken into account.

The enthalpy equation (146) includes both the sensible enthalpy and the standard-state enthalpy of formation. The entropy s^0 includes the low-temperature enthalpy of formation as also the chemical and sensible contributions.

The entropy s at any arbitrary pressure is given by:

$$s = s^0 - RT \log (p/p_0) \quad (148)$$

where p_0 = standard atmospheric pressure.

6. KINETICS DATA

The following information is required to specify the chemical kinetics of the system considered:

- the set of elementary reactions making up the assumed chemical-kinetic mechanism:
- the Arrhenius constants for each elementary reaction.

In the present study, only reactions of the following types are considered:



The forward reaction rate constant is expressed as:

$$k_{fj} = A_j T^{B_j} \exp(-T_{actj}/T), \text{ for reaction } j \quad (152)$$

The Arrhenius constants A_j , B_j and T_{actj} are supplied for each one of the reactions considered.

The reverse reaction rate constant may either be directly specified as above, or it may be calculated from a knowledge of the forward rate constant and the equilibrium constant:

$$k_{bj} = \frac{k_{fj}}{K_{cj}} \quad (153)$$

7. RESULTS AND DISCUSSIONS

7.1 Introduction

In this chapter results are presented for two test cases: one without chemical reaction (cold flow) and one with chemical reaction. Before presenting the results certain computational details are given in the next section.

7.2 Computational details

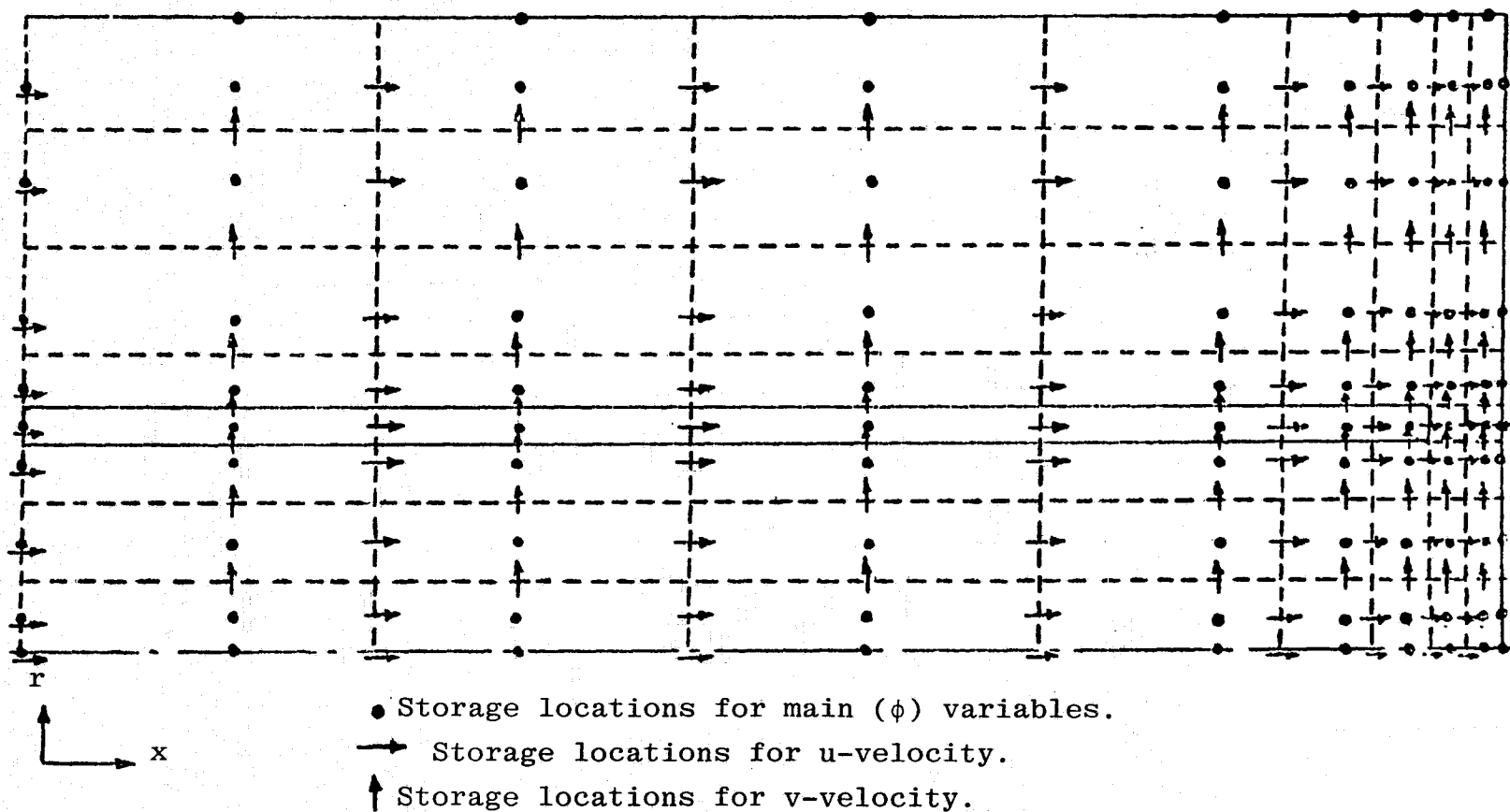
(i) Variables computed

At each grid node, 22 variables were computed for the test case with chemical reaction. The variables obtained from the solution of partial differential equations were: the axial and radial velocity components u and v , the pressure p , the stagnation enthalpy $\hat{h}$, the mixture fraction f , the mass fraction of unburnt fuel m_{fu} , and the mass fractions of the species N , NO , NO_2 , and N_2O . The variables obtained through the use of auxiliary algebraic equations were: the mass fractions of the species CO , CO_2 , H , H_2 , H_2O , N_2 , O , OH , and O_2 , density, effective viscosity and temperature.

For the test case without chemical reaction, the variables u , v and p were obtained from the solution of partial differential equations, and the effective viscosity from an auxiliary algebraic equation.

(ii) Grid used:

The grid used in both the test cases had 10 nodes in the axial and in the radial directions. The distribution of the nodes was non-uniform in both the directions and is illustrated in Fig. 11.



Scale: 1:1 axial, 10:1 radial.

Fig. 11: Grid distribution for test cases.

(iii) Convergence:

The convergence criteria adopted were:

- The normalised residual errors of each of the variables u , v , $\hat{h}$, f and m_{fu} which were solved by a line-by-line procedure, should be less than 0.5%.
- The mass fractions of N , NO , NO_2 , and N_2O which were obtained by a point-by-point solution procedure should remain within 0.1% of their values from one iteration to the next.

(iv) Physical and chemical data:

The thermochemical data for all the species were obtained from Ref. 2. Reaction rate data are given in Table 2.

(v) Geometrical and other data:

The parameters defining the two test cases are given in Table 3.

7.3 Results of Test Case 1

The problem specification for test case 1 is given in Table 3. This case in which chemical reaction is not considered is not of much practical interest and the aim in performing it was mainly to test the hydrodynamic features of the computer code.

Figure 12 shows the axial velocity profile at various cross-sections of the combustor. The behaviour is as expected. On entry into the duct, the fuel and air jets exhibit mixing and towards the end of the inner duct the flow shows signs of approaching developed pipe flow. Radial momentum effects are of some importance at the entrance of the duct, but for the bulk of the flow in the inner duct, radial momentum effects are

Table 2. Reaction rate data (in S.I. Units)

No.	Reaction		A	B	T _{act}	Ref.
1	N+NO	N ₂ +O	1.500E10	0	0	3
2	N+O ₂	NO+O	5.998E6	1.0	3.172E3	3
3	OH+N	H+NO	5.998E8	0.5	4.028E3	3
4	H+N ₂ O	OH+N ₂	7.998E10	0	7.553E3	3
5	N ₂ O+O	NO+NO	1.000E11	0	1.500E4	3
6	N ₂ O+M	N ₂ +O+M	1.000E11	0	2.518E4	3
7	N+O+M	NO+M	6.397E10	-0.5	0	6
8	NO ₂ +O	NO+O ₂	1.000E10	0	3.000E2	6
9	NO ₂ +M	O+NO+M	1.099E13	0	3.300E4	6

Forward rate constant $k_f = AT^B \exp(-T_{act}/T)$

Reverse rate constant obtained from forward rate and equilibrium constants.

Hydrocarbon oxidation reaction rate = $0.01 m_{fu} m_{ox} \exp(-18000/T)$

Table 3: Specification of Test Cases

$T_{ao} = T_{fo} = 275^{\circ}\text{K}$	$m_{ao} = 3.6 \times 10^{-4} \text{ kg/s}$
$P_o = 2 \text{ atmospheres}$	$m_{fo} = 1.4 \times 10^{-5} \text{ kg/s: } (\phi=.66)$
$L_1 = 20 \text{ cm}$	$D_{1,o} = 0.7 \text{ cm}$
$L_2 = 1 \text{ cm}$	$D_{2,i} = 1.8 \text{ cm}$
$D_f = 0.1 \text{ cm}$	$D_{2,o} = 2.1 \text{ cm}$
$D_{1,i} = 0.6 \text{ cm}$	

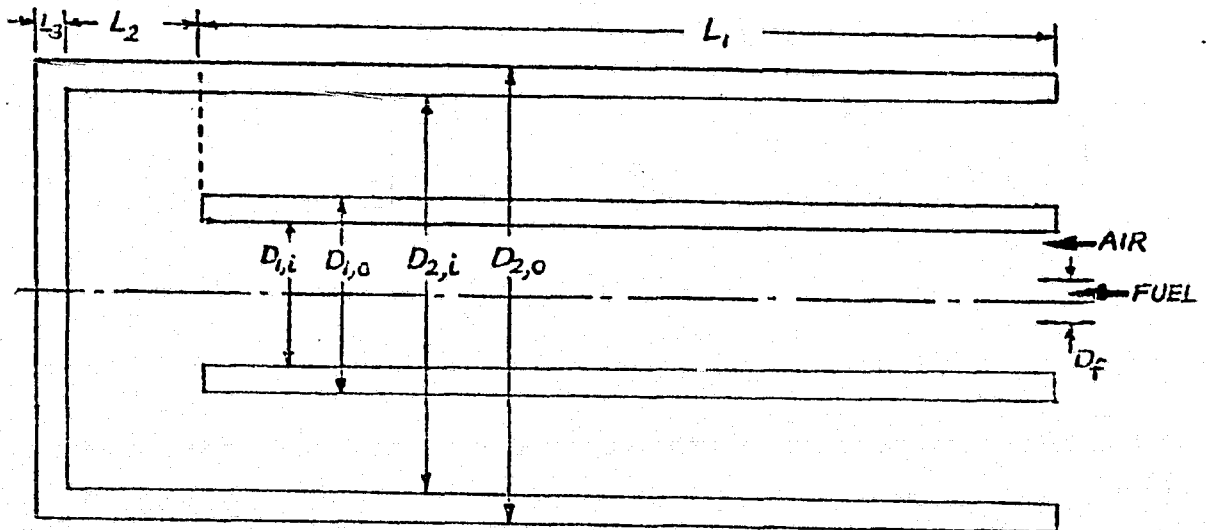
Heat transfer data (for case 2 only)

All Stanton numbers (see Sec. 4.3) = 0.003.

Conductivity of wall material = 41.84 Joules/m.sec. $^{\circ}\text{K}$.

Emissivity of all walls = 0.05.

Surroundings: temperature = 300 $^{\circ}\text{K}$;
velocity = 1 m/sec.



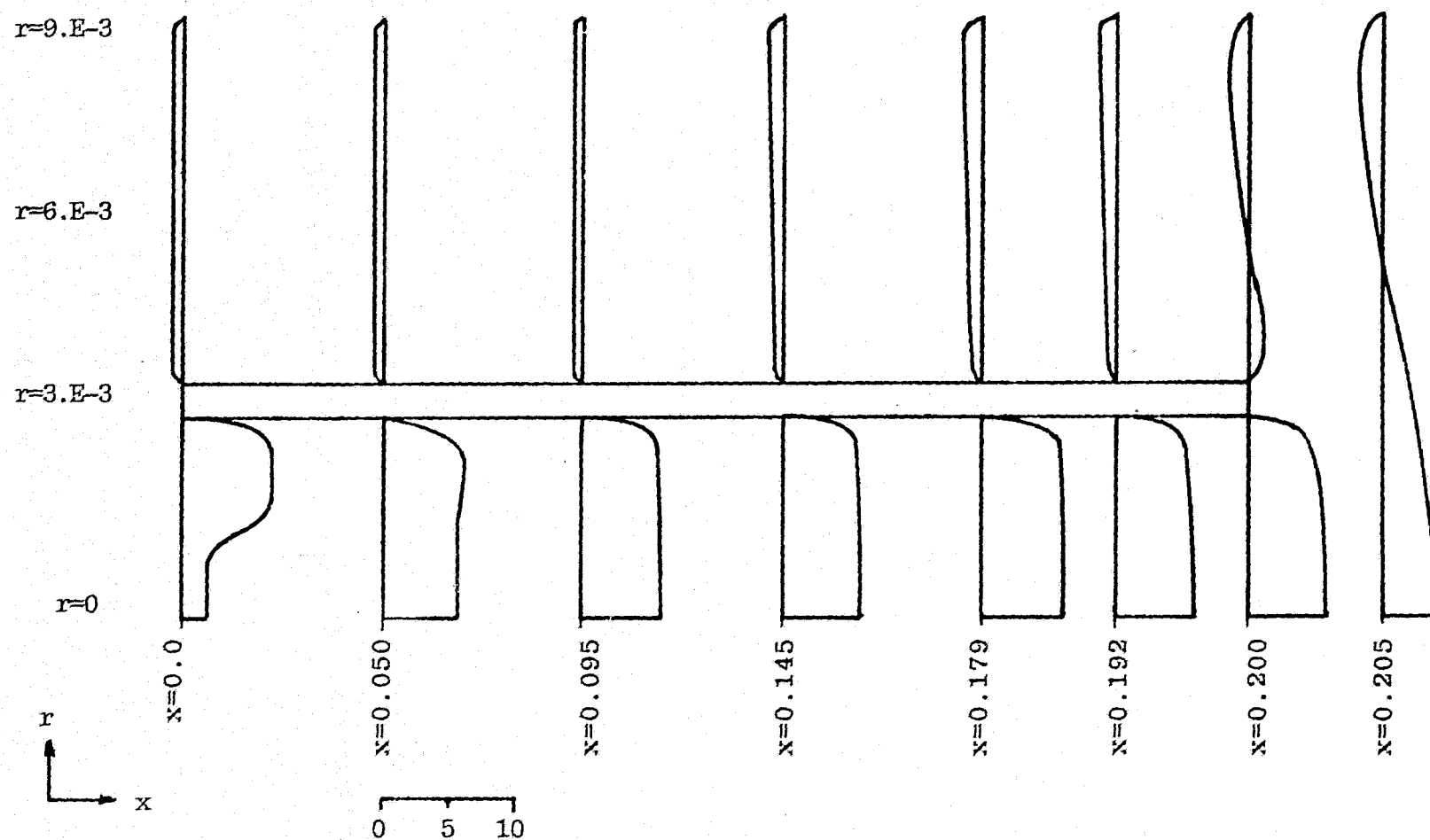


Fig. 12: Profiles of u-velocity (m/sec); Test case 1

negligible; and the pressure field is essentially uniform in the radial direction. This permits the calculation scheme to be simplified by: cutting out the solution of the radial momentum equation, assuming the pressure to be a function of axial distance alone and obtaining the radial velocity directly from the continuity equation. In the present work, however, this simplification has not been introduced, since the aim was to develop a general program which could handle different geometries in which radial momentum transfer might be significant all through the flow field.

At the end of the inner duct, flow reversal into the outer duct occurs and the pressure at the end wall rises as in stagnation flow. In the outer duct, again towards the end the flow exhibits similar characteristics as at the end of the inner duct: i.e. pressure radially uniform and radial velocities small compared to the axial velocities.

7.4 Results of Test Case 2

The problem specification for test case 2 is given in Table 3. This is the case of greater practical interest and it demonstrates all the features of the computer program.

Figure 13 shows the axial velocity profile at various cross-sections of the combustor. The behaviour is qualitatively similar to that of test case 1. Quantitatively, the velocities are slightly higher in the inner duct (as compared to test case 1); this is due to the reduced density brought about by the preheating of the incoming gases. In the outer passage, the velocities undergo a rapid increase through the flame zone as the density drops rapidly. Comments about radial momentum effects made in Section 7.3 apply to this test case also.

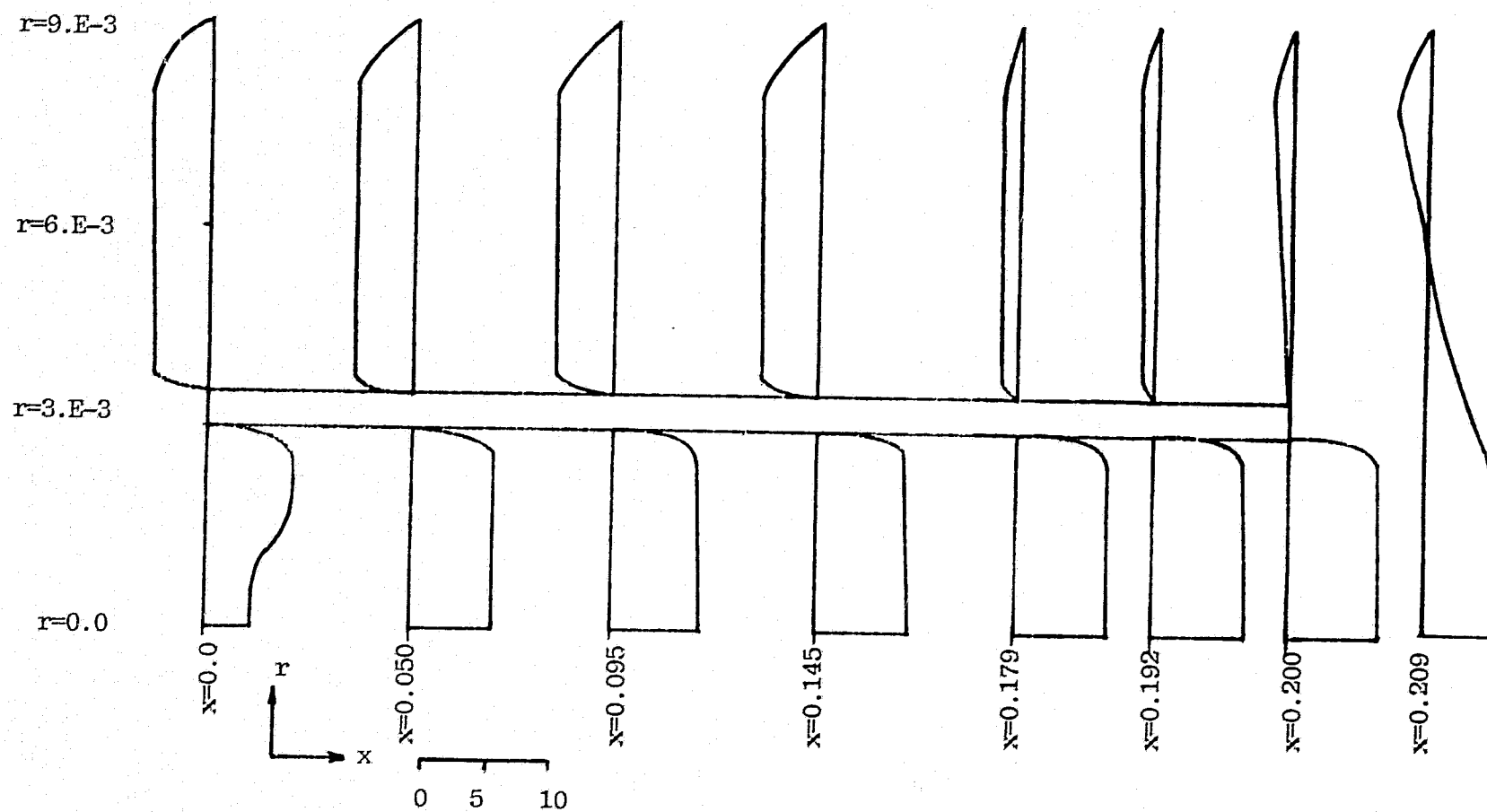


Fig. 13: Profiles of u-velocity (m/sec); Test case 2

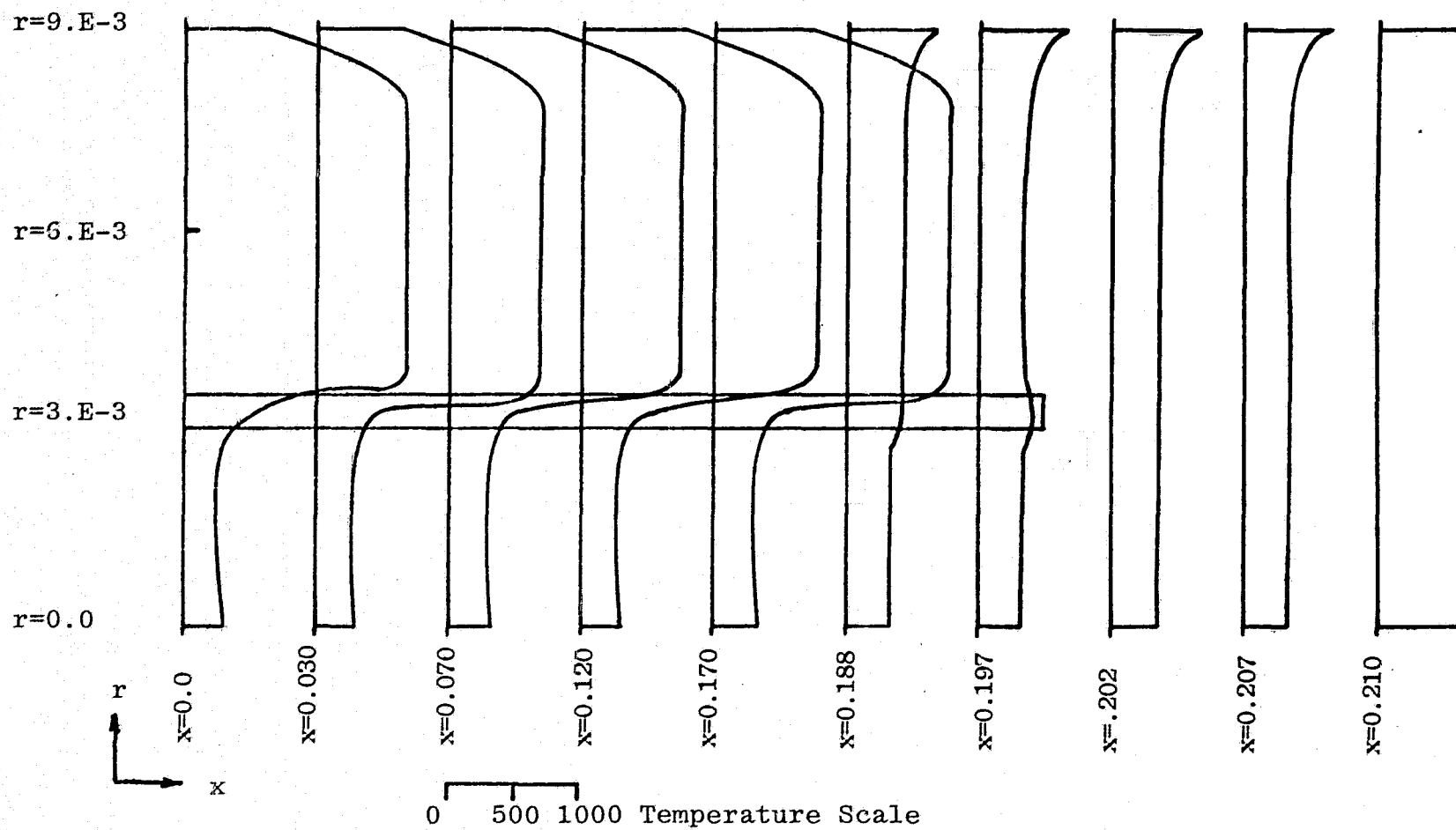


Fig.14: Profiles of temperature (degrees K)

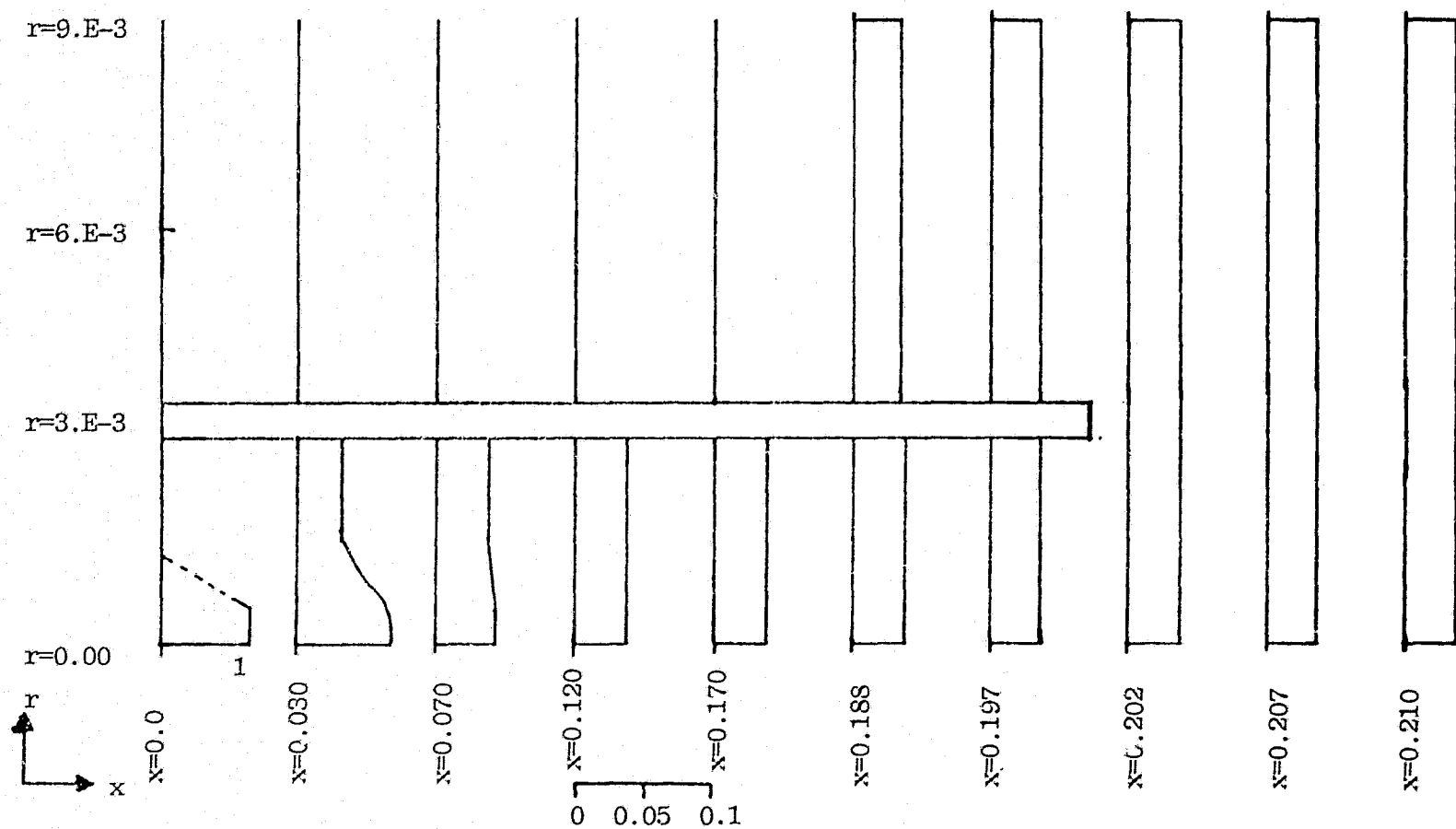


Fig. 15: Profiles of Fuel mass fraction

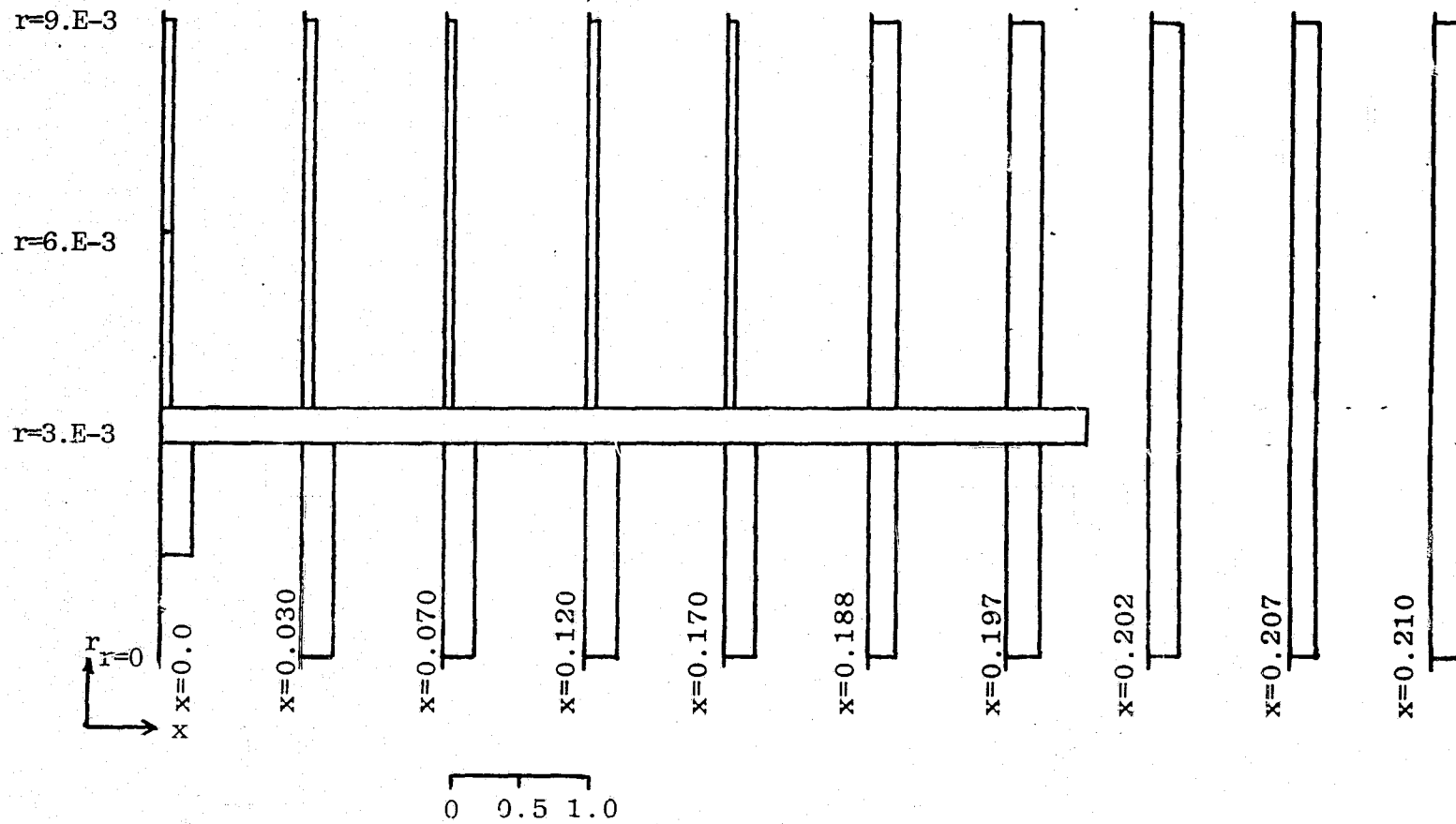


Fig. 16: Profiles of oxygen mass fraction

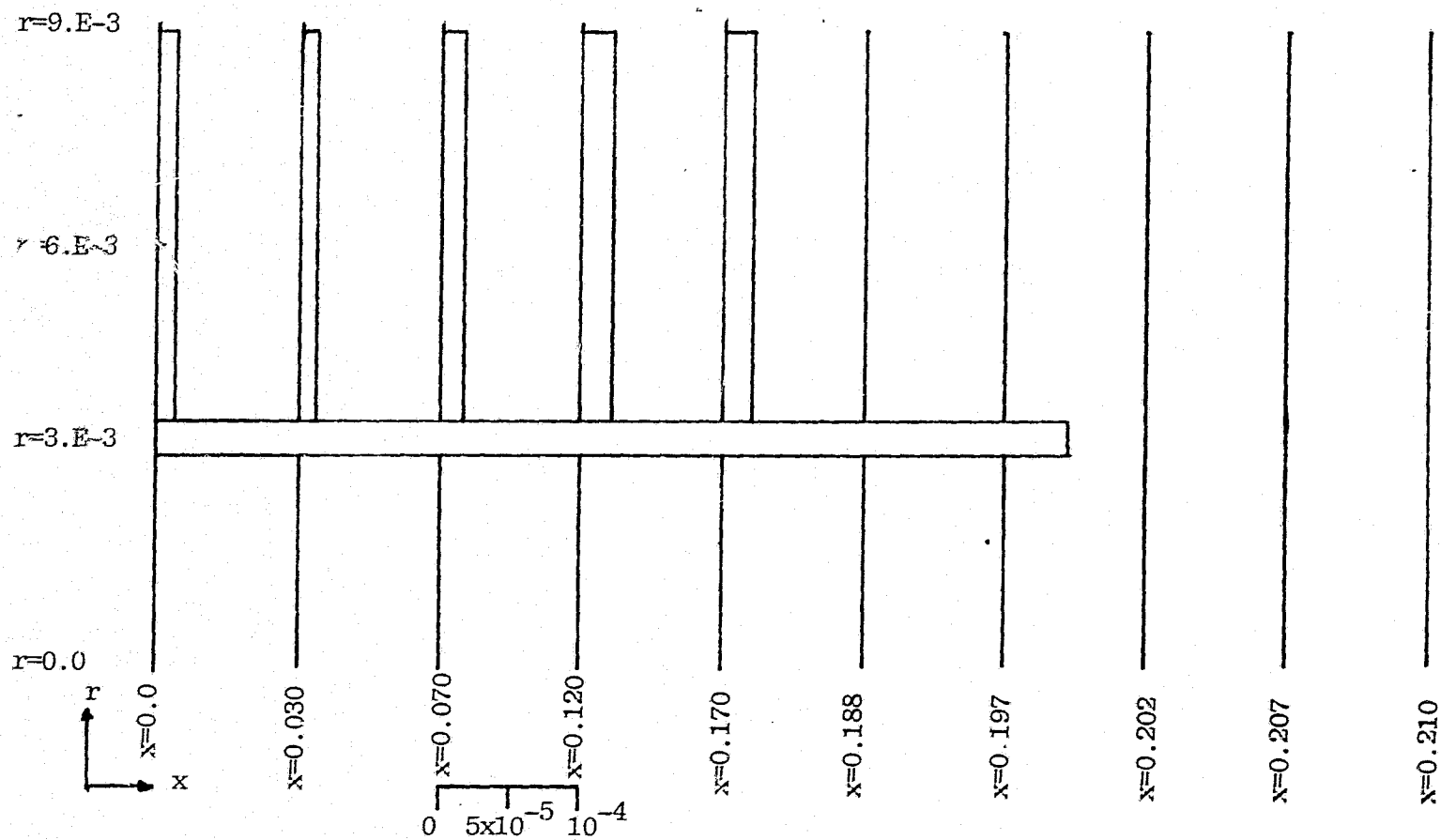


Fig. 17: Profiles of CO mass fraction

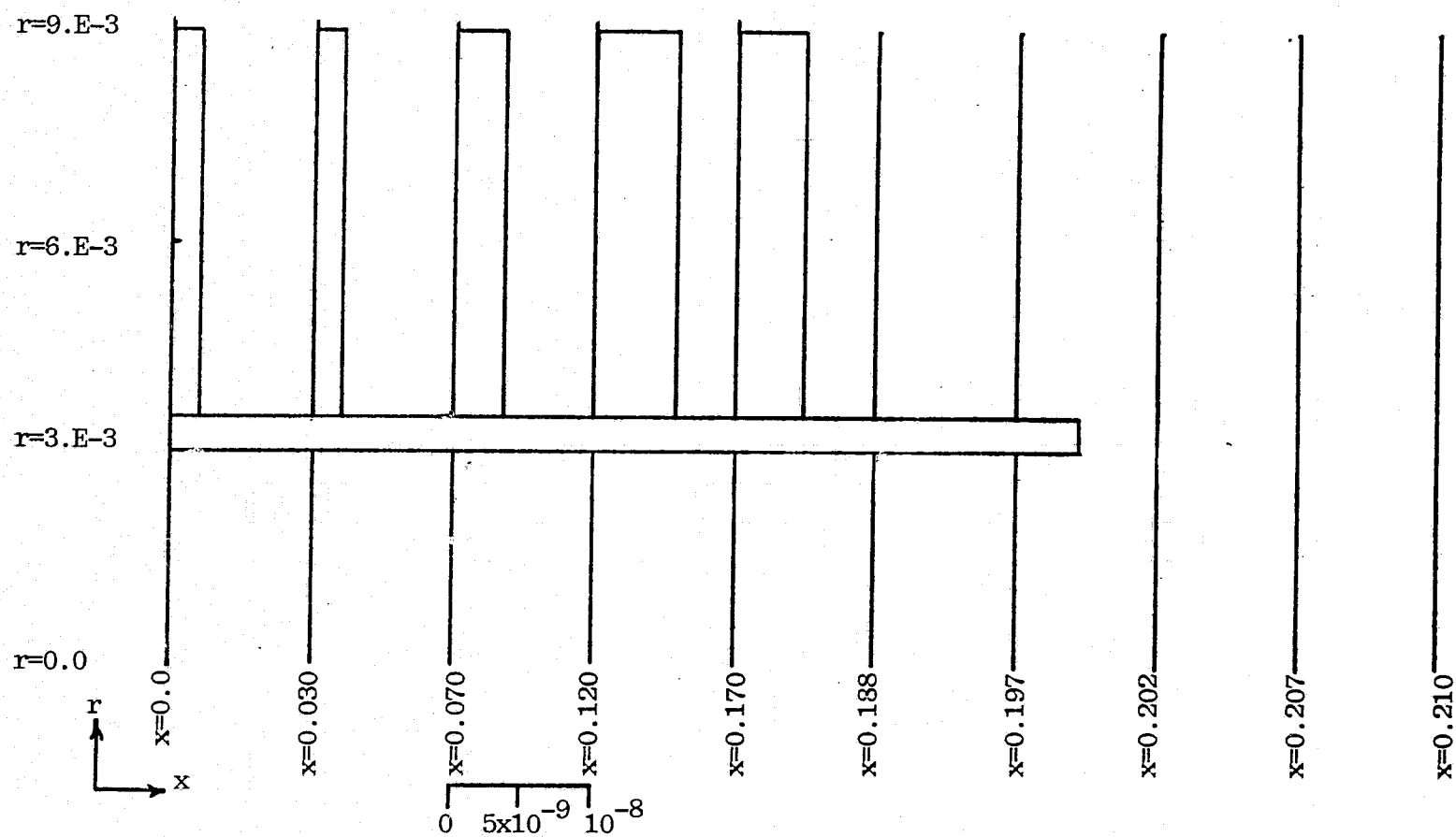


Fig. 18: Profiles of H mass fraction

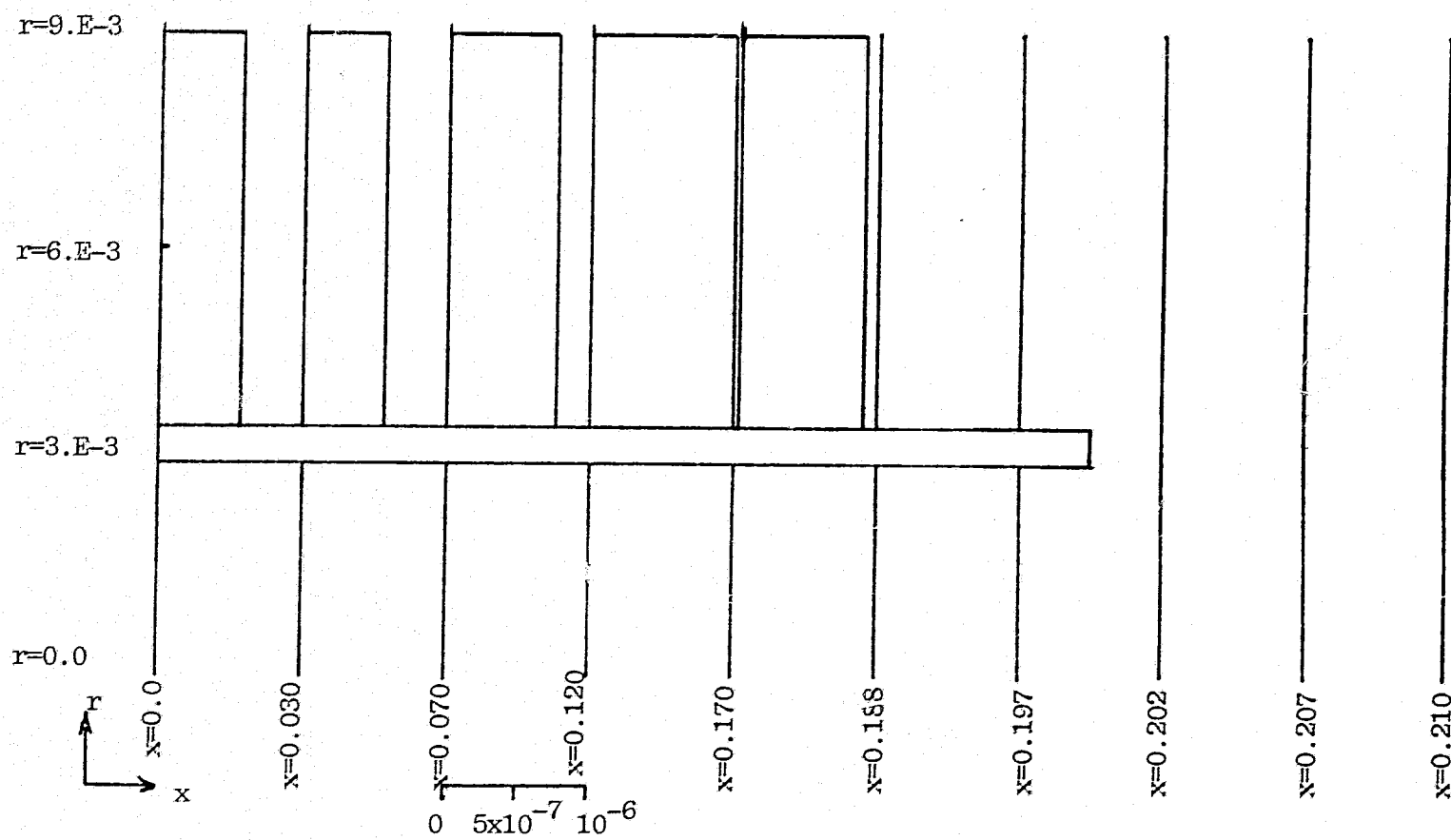


Fig. 19: Profiles of H_2 mass fraction

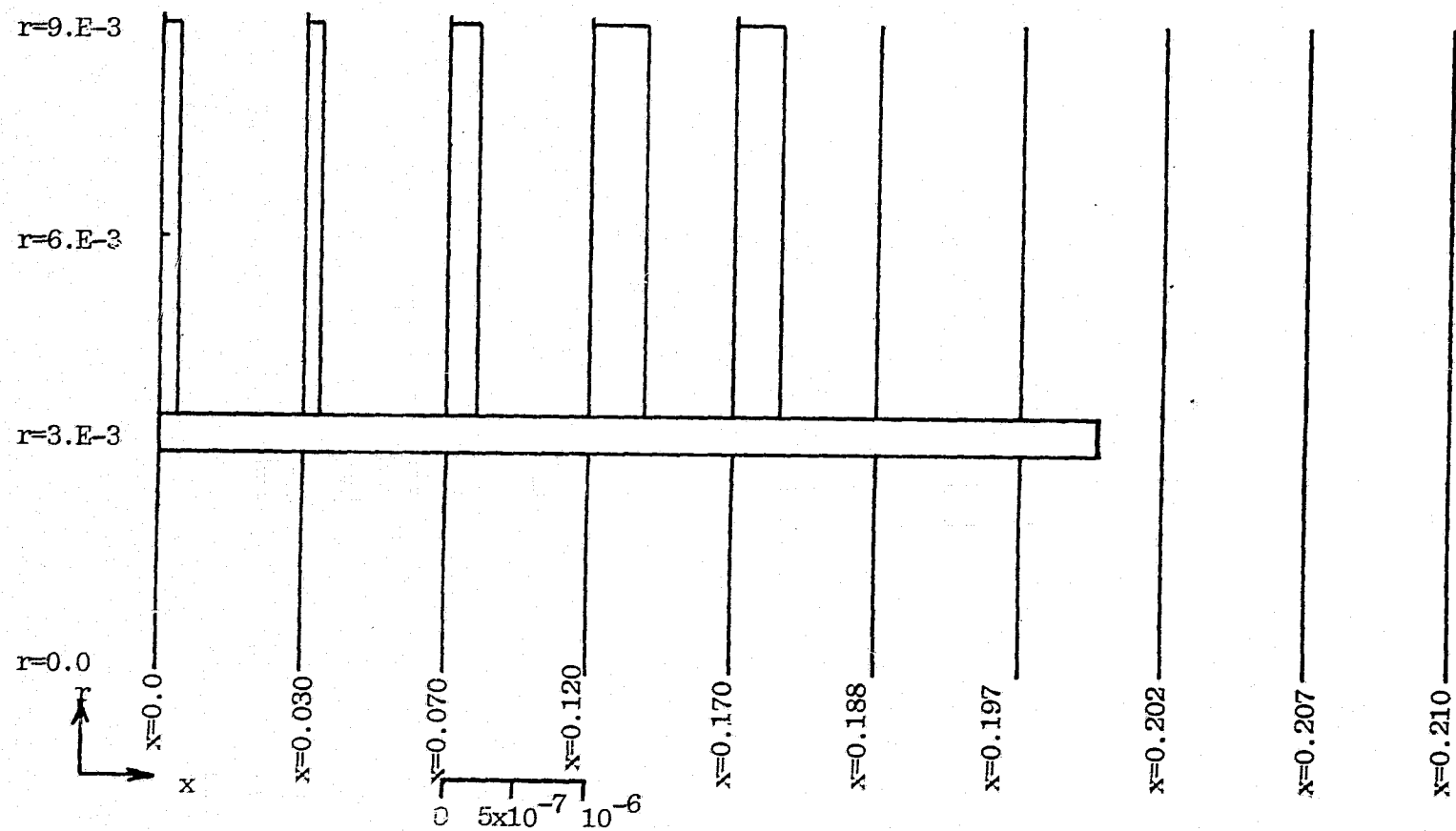


Fig. 20: Profiles of 0 mass fraction

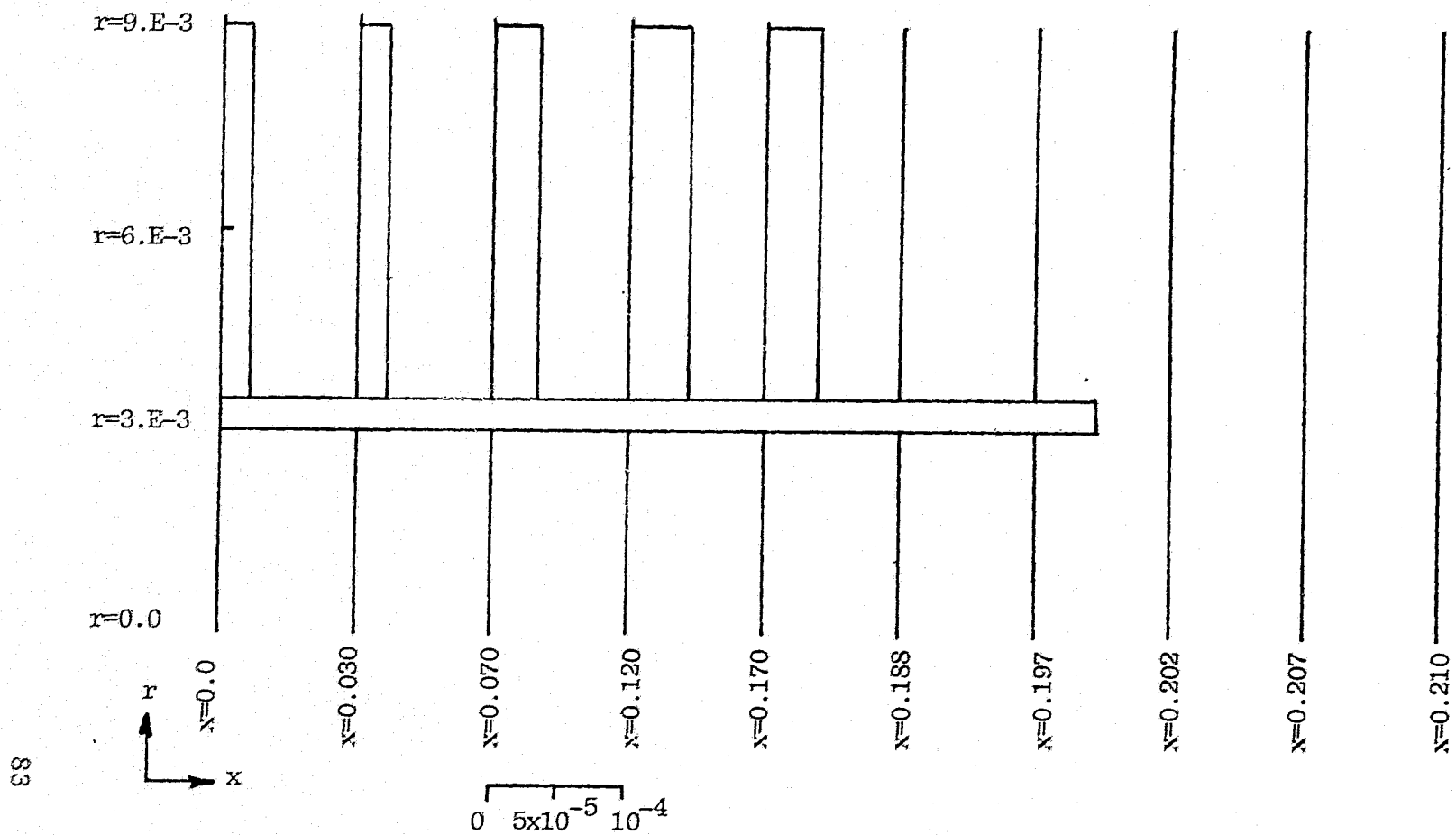


Fig. 21: Profiles of OH mass fraction

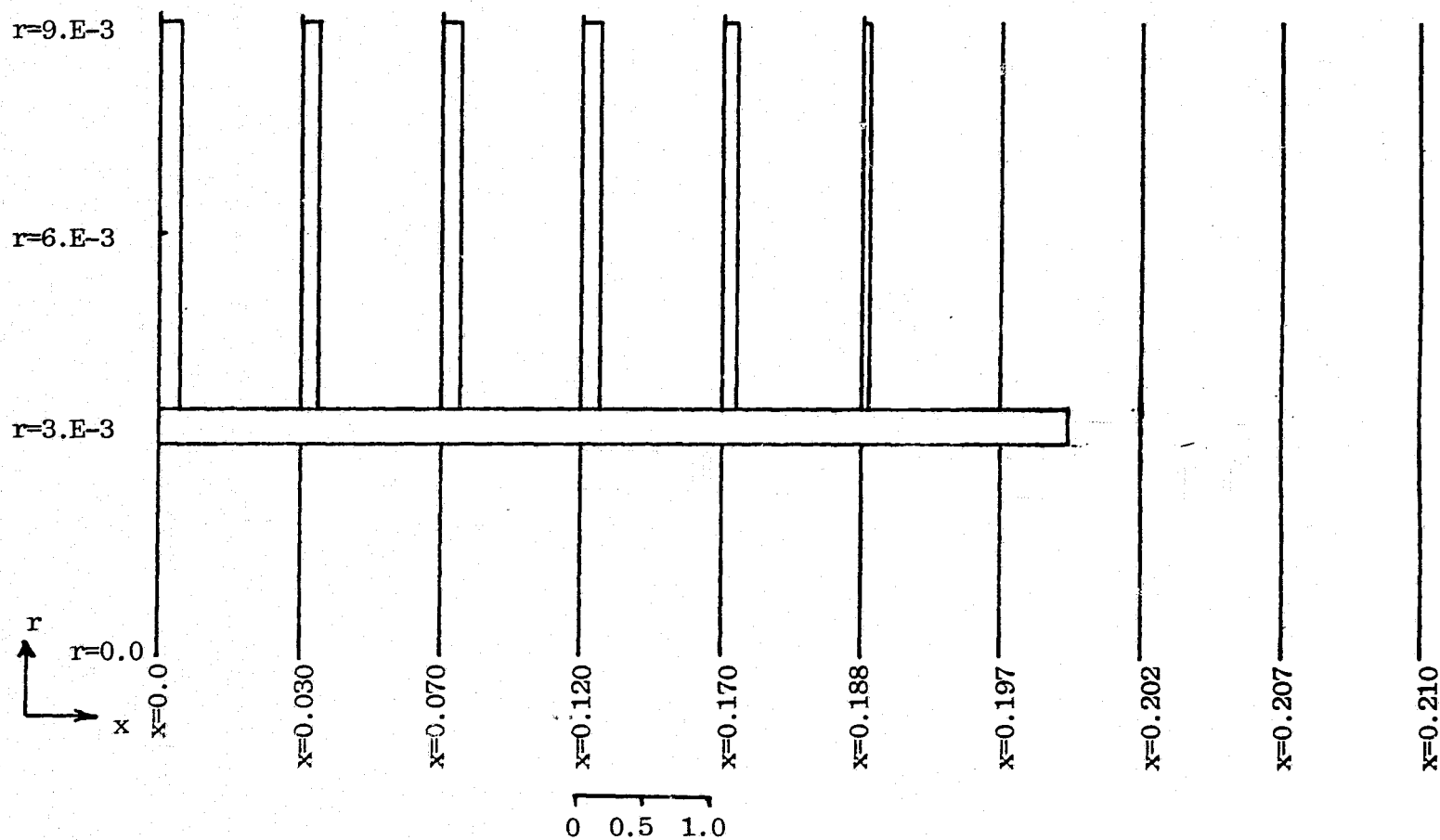


Fig. 22: Profiles of CO_2 mass fraction

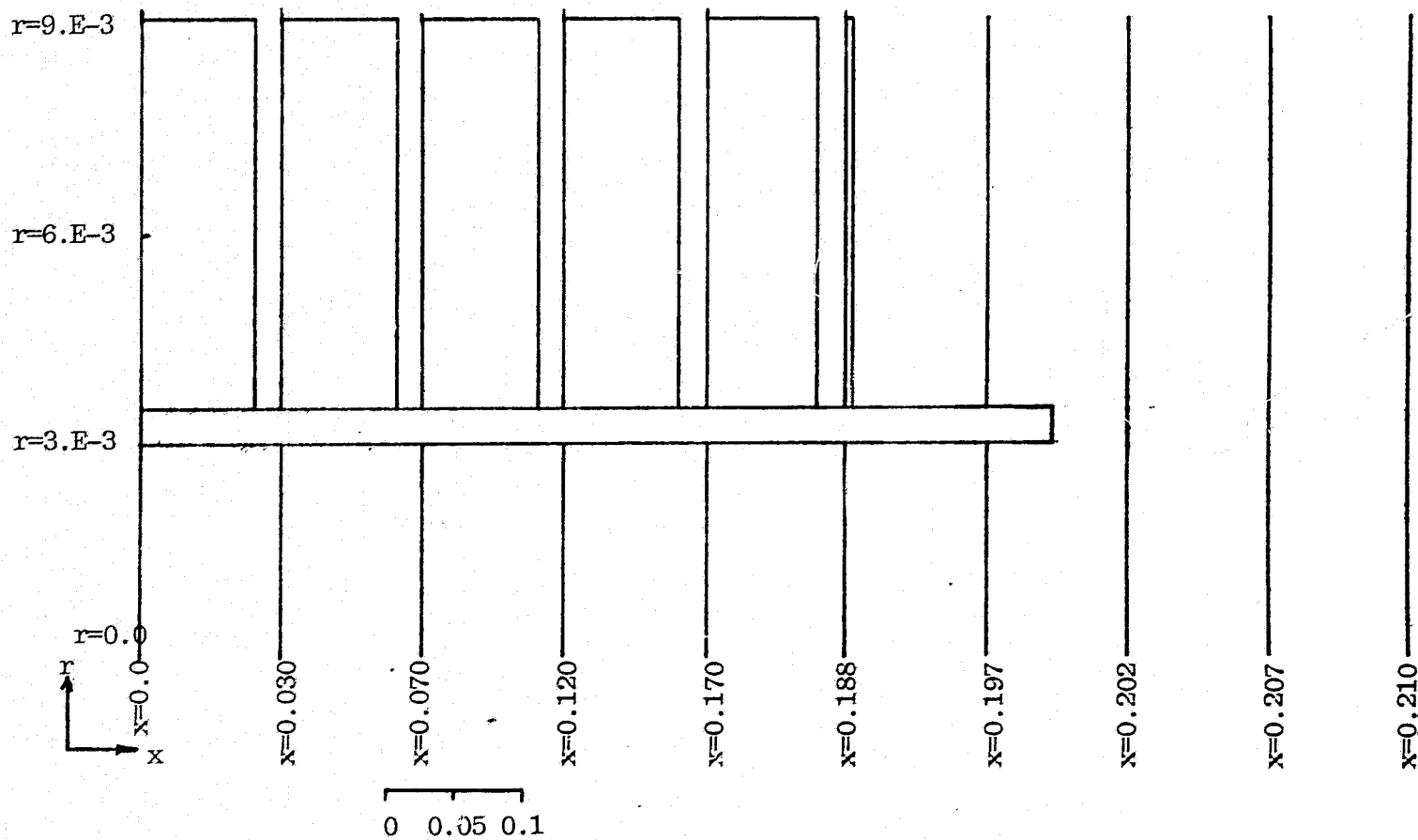


Fig. 23: Profiles of H_2O mass fraction

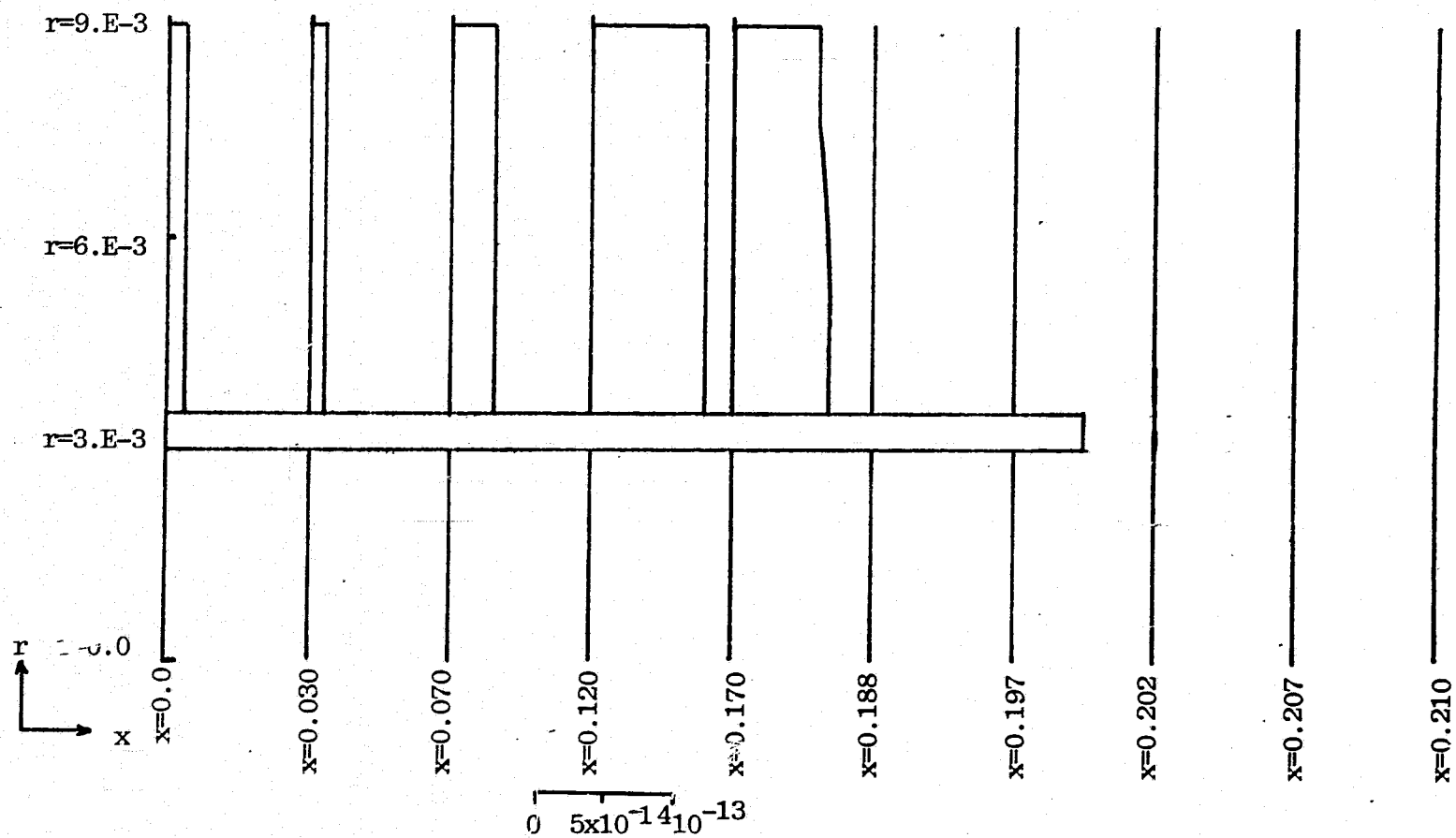


Fig. 24: Profiles of N mass fraction

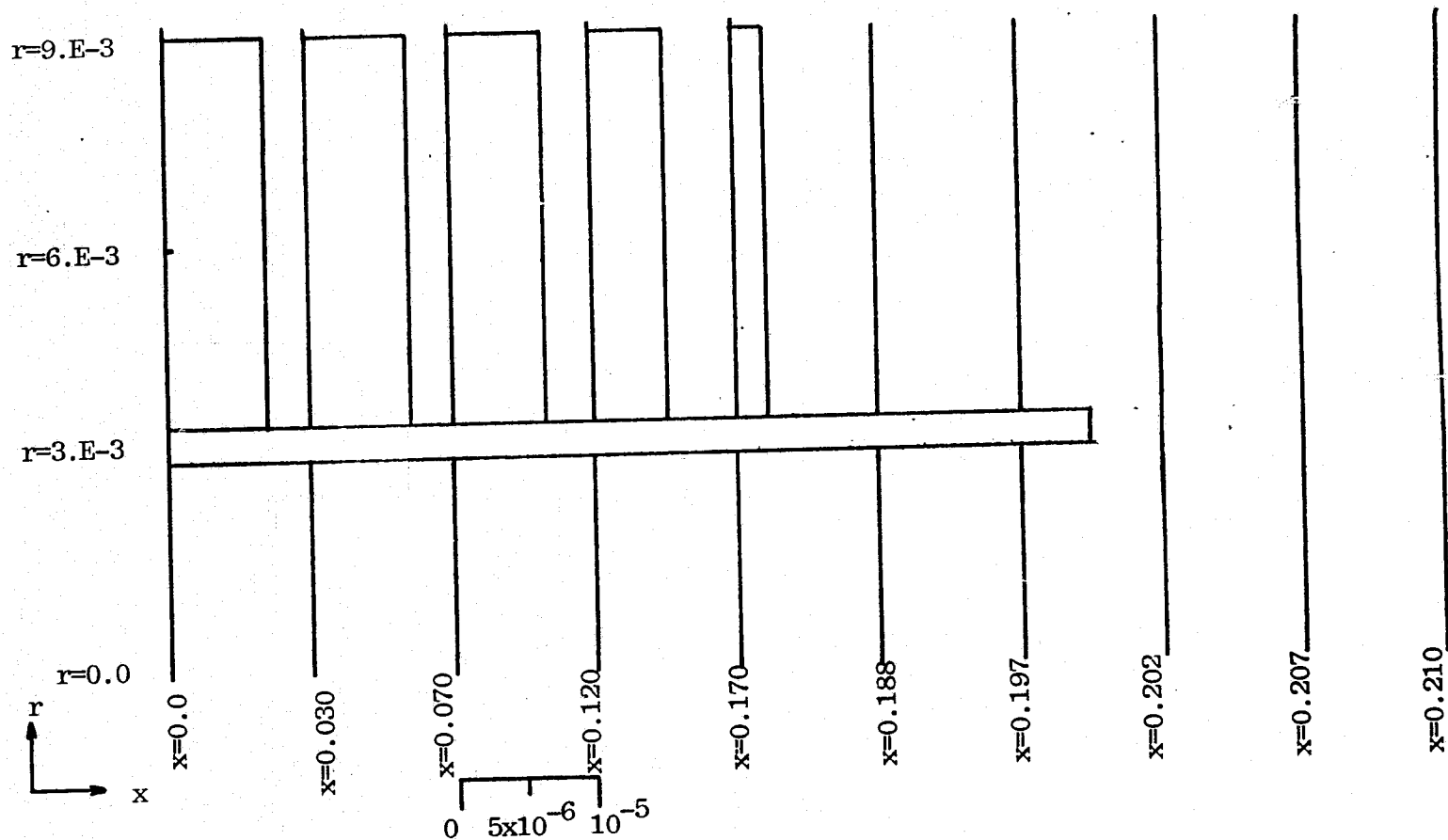


Fig. 25: Profiles of NO mass fraction

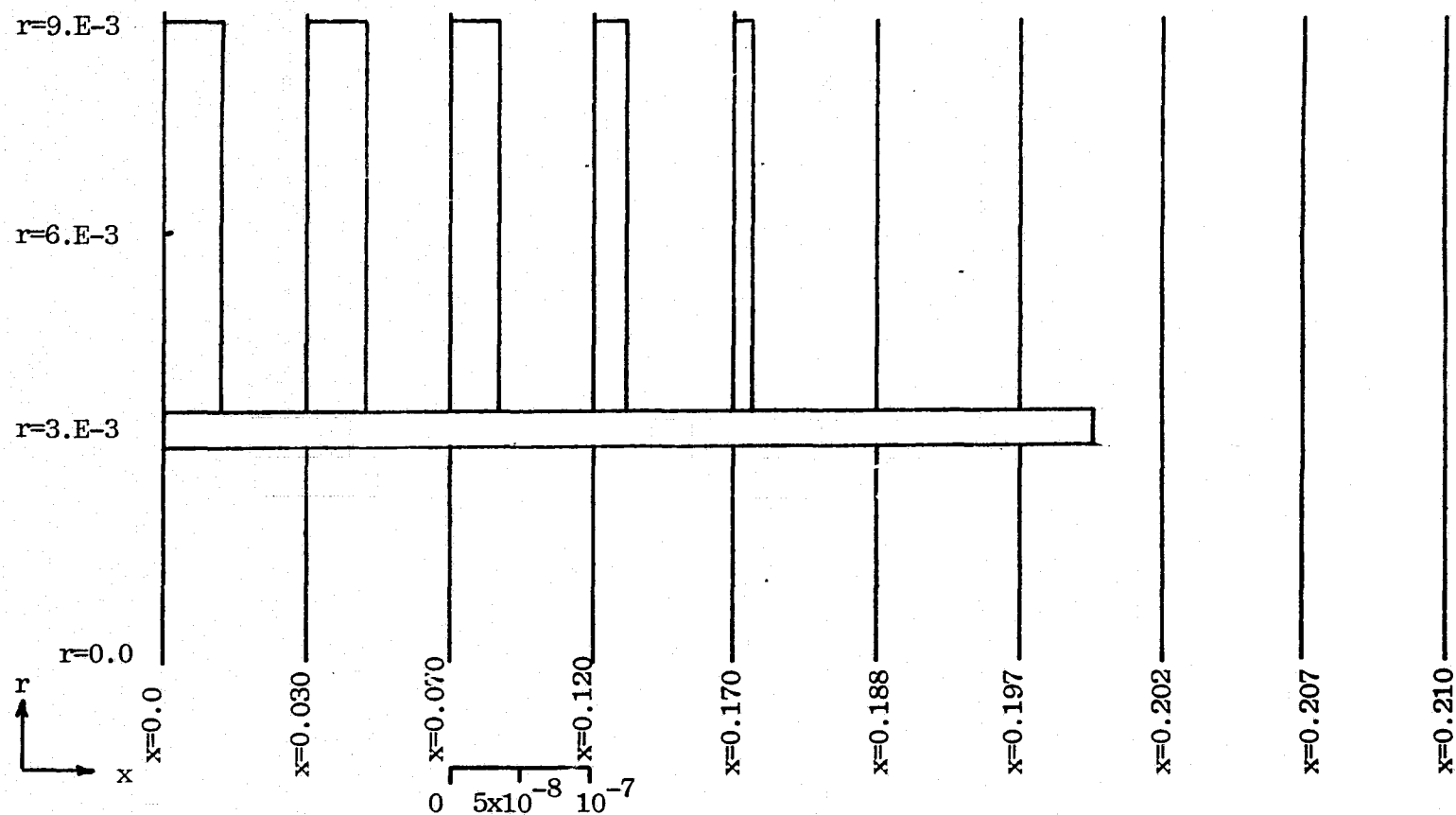


Fig. 26: Profiles of NO₂ mass fraction

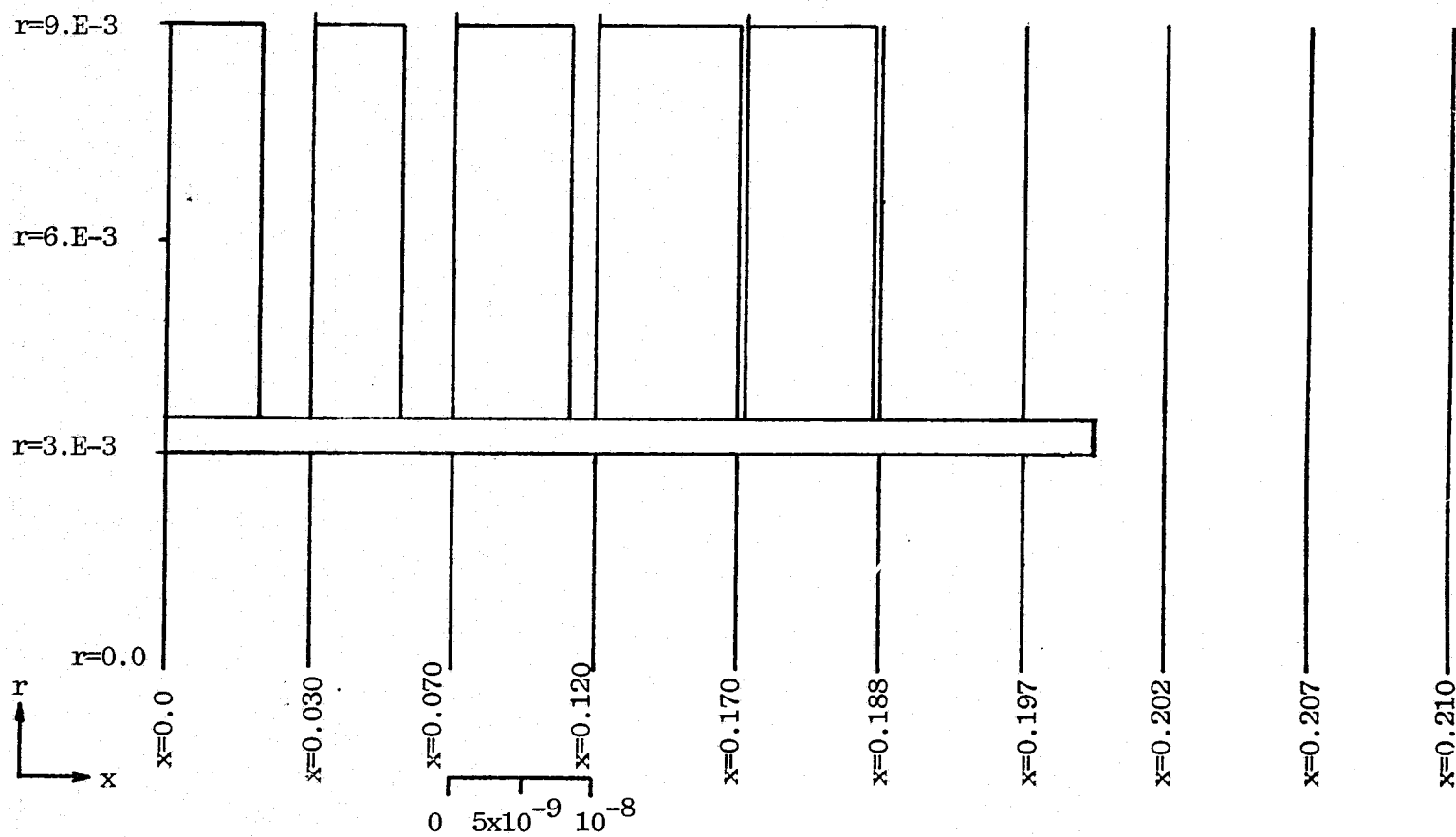


Fig. 27: Profiles of N_2O mass fraction

Figure 14 shows the temperature profile at various cross-sections of the combustor. The slight rise in temperature in the inner duct is due to the conduction of heat through the wall from the hot gases in the outer duct. After flow reversal into the outer duct, combustion occurs and the temperature rises rapidly. In the post-flame zone there is a slight drop of temperature due to heat loss to the surroundings and to the incoming gases.

Figures 15 and 16 show the fuel and oxygen profiles. In the inner duct, the air and fuel streams simply mix together and there is no reaction. Therefore at the end of the inner tube, the air-fuel mixture is almost uniformly mixed. The fuel and oxygen profiles show a decay with the passage of the gases through the flame zone in the outer duct. This behaviour is seen to be consistent with the temperature distribution. At the end, all the fuel is consumed and the excess oxygen is left unburnt.

Figures 17 to 21 show the profiles of the species CO , H , H_2 , O , and OH . These are intermediate species formed in the reaction zone. Therefore, as expected, the concentrations of these species all have a maximum value within the main reaction zone. The drop in the concentrations of these species from their maximum values as one proceeds further downstream is due to their being converted into the stabler product species CO_2 and H_2O .

Figures 22 and 23 show the profiles of the final product species CO_2 and H_2O . These show a continuous rise and levelling off in the post-flame region. The formation of these two species is consistent with the temperature rise and fuel consumption through the flame zone.

Figures 24 to 27 show the profiles of the NO_x species: N , NO , NO_2

and N_2O . The NO concentration peaks at a point slightly downstream of the main reaction zone. This behaviour is as expected since the formation of NO is governed by kinetically-controlled reactions which are much slower than the hydrocarbon-oxidation reactions which rapidly reach the equilibrium state. After reaching its maximum value, the NO concentration drops slightly due to the dropping temperature.

7.5 Conclusions

The discussion of the results of the two test cases in the preceding sections shows that the results obtained are as expected. Since only one chemically reacting test case was computed, it has not been possible to draw various conclusions about the behaviour of such combustors for different operating conditions. However, the technique for computing such flows has been successfully demonstrated.

It should also be mentioned here that the present results have been obtained with relatively coarse grids. In order to obtain more accurate results, finer grids need to be used; this of course results in increased computer time and storage, but is still within the capabilities of ordinary computers. Finer grids are needed especially in the flame zone in order to obtain better resolution in a region where sharp gradients exist.

8. CONCLUDING REMARKS

The present computer program has been successfully used to predict the hydrodynamics and chemistry in a two-concentric-tube combustor. The predictions obtained are qualitatively plausible. Detailed experimental data are required to assess quantitatively the validity of the numerical procedure and the physical hypotheses involved.

In concluding this report, some consideration is given to what further developments would be fruitful. The following improvements may be envisaged to make the program approach more towards physical realism.

(a) Turbulence modelling:

The present version of the program incorporates a simple zero-equation model of turbulence. Obviously, this is an oversimplification and a more realistic simulation of turbulence would be to employ the two-equation model employing the kinetic energy of turbulence and its dissipation rate, as the dependent variables of differential equations.

(b) Heat transfer calculations:

In the present program, the modelling of convective and radiative heat transfers has been considerably simplified. In the calculation of convective heat transfer, uniform prescribed Stanton number have been employed. A more realistic representation would be to compute the Stanton numbers locally, as done in, for example, Ref. 7.* The extension of the program to achieve this is quite straightforward.

In the calculation of radiative heat transfer, it has been

* Since the writing of this report this has been done. The corresponding update to the program is given as Appendix E.

assumed that the gas is not participating in the heat transfer process. The incorporation of a four-flux model of radiation (e.g. Ref. 8) would permit a more realistic simulation of the radiation process and would permit the absorption and scattering of radiation by the gas to be accounted for in a simple way. A further refinement would be to compute the distribution of radiation energy in wavelength space; and to allow for the multiple interactions between different parts of the combustion chamber which are the special features of the Hottel-Sarofim (Ref. 9) method. Although the extension of the present code to include these refinements is conceptually straightforward, it should be pointed out that these extensions would result in a considerable increase of both computer storage and processing times.

(c) Sophisticated chemical-kinetic models

The consideration of detailed hydrocarbon-air kinetics as distinct from a simple one-step Arrhenius expression together with the detailed NO_x -kinetics scheme used in the present work would give a more accurate prediction of NO_x -emissions. It is a simple matter to enlarge the chemical-kinetic sophistications of the present program; all that is required is to enlarge the storage requirements of the program, to extend the limits of some DO-loops, and to supply additional coding for the coupling of the species and energy equations. However, this again results in a manifold increase of computer processing time and fine-grid computations with sophisticated chemical kinetics are likely to be prohibitively expensive.

9. REFERENCES

1. Pun W M and Spalding D B, "A general computer program for two dimensional elliptic flows", Imperial College, London, Mechanical Engineering Department, Report No. HTS/76/2, 1976.
2. Gordon S and McBride B, "Computer program for calculation of complex chemical equilibrium compositions", NASA SP-273, 1971.
3. Pratt D T and Wormeck J, "CREK :A computer program for calculation of chemical reaction equilibrium and kinetics in laminar or turbulent flows", Washington State University, Pullman, Department of Mechanical Engineering, Report No. WSU-ME-TEL-76-1, 1976.
4. Patankar S V and Spalding D B, "A calculation procedure for heat, mass and momentum transfer in three-dimensional parabolic flows", Int. J. Heat Mass Transfer, vol 15, p.1787, 1972.
5. Spalding D B, "Basic equations of fluid mechanics and heat and mass transfer and procedures for their solution", Imperial College, London, Mechanical Engineering Department, Report No. HTS/76/6, 1976.
6. Baulch D L, Drysdale D D, Horne D G and Lloyd A C, "Evaluated kinetic data for high temperature reactions, Volume 2", Butterworths, London, 1973.
7. Spalding D B, "GENMIX: A general computer program for two-dimensional parabolic phenomena", Imperial College, London, Mechanical Engineering Department, Report No. HTS/77/9, 1977.

8. Lockwood F C and Spalding D B, "Prediction of a turbulent reacting flow with significant radiation", Published in Proc. Colloques d'Evian, J. de Physique, 1971.
9. Hottel H C and Sarofim A F, "Radiative transfer", McGraw-Hill, New York, 1967.
10. Elghobashi S, Spalding D B and Srivatsa S K, "Prediction of hydrodynamics and chemistry of confined turbulent methane-air flames with attention to formation of oxides of nitrogen", NASA CR-135179, 1977.
11. Bird R B, Stewart W E and Lightfoot E N, "Transport phenomena", Wiley, New York, 1960.
12. Rohsenow W M and Hartnett J P, "Handbook of heat transfer", McGraw-Hill, New York, 1973.
13. Jayatilaka C V L. "The influence of Prandtl number and surface roughness on the resistance of the laminar sub-layer to momentum and heat transfer". Progress in Heat and Mass Transfer, Vol. 1, Ed. by Grigull U and Hahne E, Pergamon Press, London.

10. NOMENCLATURE

Note: Some symbols are defined and used locally in the report;
these are not included in the list below:

<u>Symbol</u>	<u>Meaning</u>
a	Cell area
a_{ij}^L	Number of kg - atoms of element i per kg mole of species j .
A_i, B_i, C_i, D_i	Coefficients in the finite-difference equations.
A_E, A_N, A_S, A_W	Finite-difference coefficients.
A_j, A_{-j}	Arrhenius pre-exponential factor.
b_j	Number of kg-atoms of element i per kg of mixture.
B_j, B_{-j}	Exponent on temperature in Arrhenius rate expression.
C	Convection mass flux.
C, C_p	Specific heat at constant pressure of the mixture.
$C_{p,j}$	Constant-pressure specific heat of chemical species j .
$D_{1,i}, D_{1,0}, D_{2,i}, D_{2,0}, D_f$	Dimensions of combustor (See Fig. 1).

<u>Symbol</u>	<u>Meaning</u>
D	Diffusion mass flux.
e_1, e_2	Emissivities; 1=inner tube; 2=outer tube.
E	Activation energy.
E	Constant in wall function.
f	Mixture fraction.
f_{st}	Stoichiometric value of mixture fraction.
g_j	Ideal-gas partial molal specific Gibb's function of species j , per kg-mole.
h	Convection heat transfer coefficient.
$\tilde{h}$	Stagnation enthalpy.
h_j	Enthalpy of chemical species j .
h_{mix}	Mixture enthalpy (sensible + chemical).
J_{diff}	Diffusion mass flux.
J_j	Diffusion mass flux.
k	Thermal conductivity.
k_b	Backward reaction rate constant.
k_f	Forward reaction rate constant.
K_c	Equilibrium constant.
L_1, L_2, L_3	Dimensions of combustor (see Fig. 1).
m_{ao}	Air flow rate.
m_{fo}	Fuel flow rate.
m_{fu}	Mass fraction of unburnt fuel.
m_j	Mass fraction of chemical species j .

<u>Symbol</u>	<u>Meaning</u>
m_{ox}, m_{O_2}	Mass fraction of oxygen.
M	Number of chemical reactions.
n	Mole number.
$n_j^{'}$	$\overset{NS}{= \sum_{i=1} \alpha_{ij}^{'}} = \text{Molecularity of forward reaction } j.$
$n_j^{''}$	As $n_j^{'}$, but for backward reaction j.
NLM	Number of elements.
NS	Number of chemical species in the system.
NSE	Number of chemical species whose concentrations are determined by a chemical-equilibrium analysis.
NSK	Number of chemical species whose concentrations are kinetically determined.
p	Pressure.
P	Arrhenius pre-exponential factor.
P_o	Initial pressure.
P_o	Standard atmospheric pressure.
Pr	Laminar Prandtl number.
Pr_{eff}	Effective Prandtl number.
Q	Heat flux.
Q_{rad}	Radiation heat flux.

<u>Symbol</u>	<u>Meaning</u>
r	Radius.
$r_{1,i}, r_{1,0},$ $r_{2,i}, r_{2,0}, r_f$ $r_{1,m}$ and $r_{2,m}$	Radii corresponding to $D_{1,i}, D_{1,0}, D_{2,i},$ $D_{2,0}, D_f$ respectively (See Fig. 1.). $=0.5(r_{1,i}+r_{1,0})$ and $0.5(r_{2,i}+r_{2,0})$ respectively.
R	Universal gas constant.
R_j, R_{-j}	Mass rate of creation of species by forward and reverse reactions j , respectively.
s	Shear stress coefficient.
s	Mass of oxygen per unit mass of fuel in stoichiometric combustion.
s_j	Ideal-gas specific entropy of species j .
s_j^o	One-atmosphere value of s_j .
Sc	Schmidt number.
St	Stanton number.
S_u, S_p	Parts of linearised source term.
S_ϕ	Source term of dependent variable ϕ .
T	Temperature.
$T_{act,j}$	Activation temperature for reaction j , i.e. activation energy divided by the universal gas constant.
T_{ao}	Air temperature at initial axial position.
T_{fo}	Fuel temperature at initial axial position.
u	x-direction velocity-component.

SymbolMeaning

u_{ao}	Air velocity at initial axial position.
u_{fo}	Fuel velocity at initial axial position.
U	Overall heat transfer coefficient.
v	r- or y- direction velocity-component.
$\bar{W}$	Mean molecular weight of gas mixture.
W_j	Molecular weight of chemical species j.
x	Axial distance.
x	Number of kg-atoms of carbon per kg-mole of hydrocarbon fuel.
y	Radial distance.
y	Number of kg-atoms of hydrogen per kg-mole of hydrocarbon fuel.
$Z_i (i=1,7)$	Coefficients in thermochemical data equations.

Greek Symbols

$\alpha'_{ij}, \alpha''_{ij}$	Stoichiometric coefficients of species i in chemical reaction j, as a reactant and as a product respectively.
α_j	Third-body stoichiometric coefficient in reaction j.
α_p	Under-relaxation factor for pressure.
γ	Ratio of specific heats (C_p/C_v).

Greek SymbolsMeaning

Γ_ϕ	Exchange coefficient for dependent variable ϕ .
δ_{ik}	Kronecker delta function.
$\delta x, \Delta x$	Grid distance in x-direction.
κ	Von Karman constant.
$\delta y, \Delta y, \delta r, \Delta r$	Grid distance in r- or y-direction.
η	Under-relaxation parameter.
λ	Thermal conductivity.
μ, μ_{eff}	Effective viscosity.
μ_l	Laminar viscosity.
ξ	Defined as $(m_{fu} - m_{ox})/s$.
ξ_{fu}	Defined as $(m_{fu})_{inlet}$.
ξ_{ox}	Defined as $-(m_{ox})_{inlet}/s$.
π_i	Lagrange multipliers in Gibbs function minimisation equation.
ρ	Density.
σ	Stefan-Boltzmann constant.
σ_j	Mole numbers of species j, kg-moles j/kg mixture.
σ_j^*	Average of σ_j over adjacent nodes, weighted by respective finite-difference coefficient.
σ_m	Reciprocal of mean molecular weight of gas mixture $= \sum_{i=1}^{NS} \sigma_i.$

Greek SymbolsMeaning

ϕ	Dependent variable.
ϕ	Equivalence ratio.
τ	Shear stress.

Subscripts

b	Fully burnt.
E,N,S,W	East, North, South, West nodes respectively.
$\sim$ h	Stagnation enthalpy.
i	i'th location in the grid.
j	Chemical species j.
NW	Near wall node.
pr	Products
P	Grid node P.
Surr	Surroundings.
wall	Wall values.
ϕ	Dependent variable ϕ .
o	Previous iteration value.
∞	Free stream value.
1,i	Inner side of inner tube.
1,0	Outer side of inner tube.

SubscriptsMeaning

2,i	Inner side of outer tube.
2,0	Outer side of outer tube.
*	'Starred' values.

APPENDIX A

ORGANISATION OF THE NASCO II COMPUTER PROGRAM*

A.1 Introduction

The organisation of the computer program will be looked at in detail in this Appendix. Firstly the structure and the interconnections of the different subroutines are described. The subroutines are classified into different categories depending on the function they serve in the program, and then each of the subroutines is described in detail. In the course of this description are mentioned the program changes necessary to solve problems with different initial and boundary conditions, and also incorporation of alternative physical modelling for properties.

The present program has been derived and developed from the CHAMPION 2/E/FIX program of Pun and Spalding (Ref. 1). The reader is advised to refer to the description of this program for background information.

A.2 Program Structure

A.2.1 Flow Diagram

The structure of the computer program can be represented by the flow diagram given on the next page. Not all the interconnections are shown here, but the ones which are shown are the main ones.

There are 18 subroutines: BLOCK DATA, MAIN, OUTPUT, PRINT, BOUND, SOURCE, WALL, CHEM, SPECE, CALC, CONST, GEOM, ADJUST, FLOWM, COEFF,

* NASCO II stands for NASA Surface Combustor, Version II.

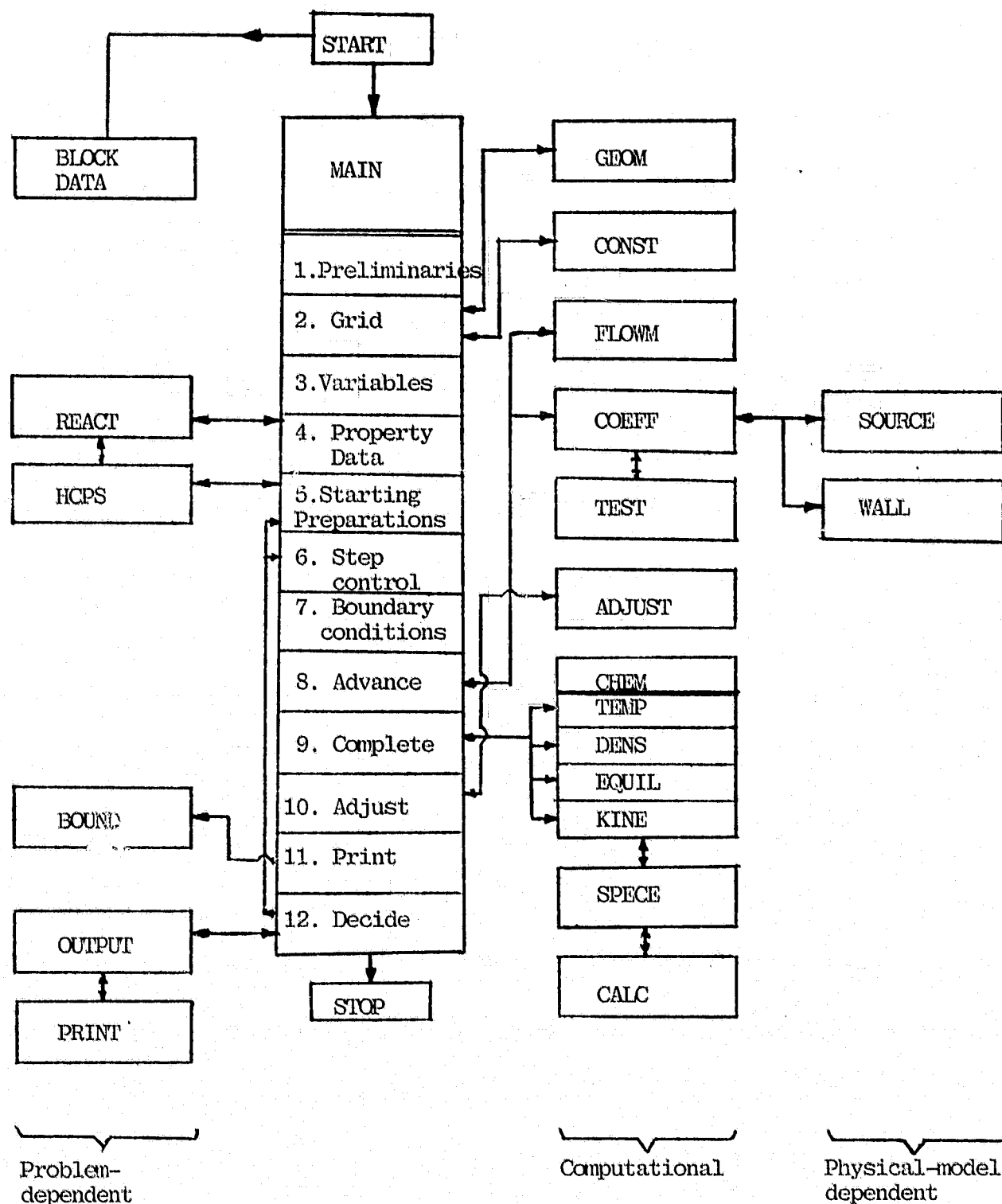


Fig. A.1: FLOW CHART OF NASCO II

TEST, REACT, and HCPS.

The first five are of major concern to the user and they will require at least minor modifications when a new problem is to be tackled. The other subroutines will in general require no modifications. Subroutines SOURCE and WALL embody the physical processes; modifications to these are needed only if alternative physical models are to be considered. Subroutines CHEM, SPECE and CALC relate to chemical-equilibrium and kinetics calculations: these should not be altered. Subroutine REACT is for the input of thermochemical and kinetics data and subroutine HCPS for the calculation of certain thermodynamic quantities. Finally subroutines CONST, GEOM, ADJUST, FLOWM, COEFF and TEST, embody the mechanisms for solving the finite-difference equations; these again should not be altered unless major extensions of the program are envisaged.

A.2.2 Flow of control

Inspection of subroutine MAIN in the flow diagram reveals that, apart from calls to certain subroutines control proceeds from the start to the end of Chapter 5.

The main computation loop is entered at the end of Chapter 5. The loop 5-6-7-8-9-10-11-12-5 is then traversed as many times as there are forward steps and number of iterative sweeps. During the course of this traverse, calls are made to various subroutines. Finally subroutine OUTPUT is called to print the results as indicated in the flow diagram.

Before describing the various subroutines, a few general comments on the storage of the variables in the program are made.

A.2.3 Storage of variables

The field variables are:

$u \langle x, y \rangle$	$\rightarrow$	$U(I)$
$v \langle x, y \rangle$	$\rightarrow$	$V(IV)$
$\tilde{h} \langle x, y \rangle$	$\rightarrow$	$H(I)$
$f \langle x, y \rangle$	$\rightarrow$	$FM(I)$
$m_{fu} \langle x, y \rangle$	$\rightarrow$	$FUE(I)$
$m_j \langle x, y \rangle$	$\rightarrow$	$FS(I, J)$
$p \langle x, y \rangle$	$\rightarrow$	$P(IP)$
$p' \langle x \rangle$	$\rightarrow$	$PP(IY)$
$\mu_{eff} \langle x, y \rangle$	$\rightarrow$	$EMU(I)$
$T \langle x, y \rangle$	$\rightarrow$	$TEM(I)$
$\rho \langle x, y \rangle$	$\rightarrow$	$RHO(I)$

In general the storage of $\phi \langle x, y \rangle$ is arranged as follows:
for the first row of grid nodes, $IX = 1$, there are NY values of ϕ , and these values fill the first NY elements of $PHI(I)$; the next NY elements of $PHI(I)$ are filled by the values of ϕ for the next row of nodes, $IX = 2$. Thus each row of nodes is sequentially stacked to fill the PHI array.

Therefore for a $NX*NY$ grid the total number of elements of the PHI array is $NX*NY$.

The sizes of the field arrays for the various variables are now summarised:

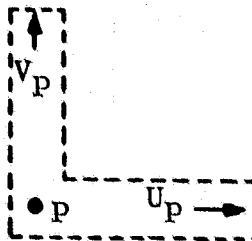
+ The notation $\phi \langle x, y \rangle$ means ϕ is a function of x and y .

<u>Variable</u>	<u>Array Size</u>	<u>Comment</u>
u	(NX-1)*NY	Storage is provided for one less row of cells due to staggering of the grid.
v	NX*(NY-1)	storage is provided for one less strip of fixed IY cells due to staggering of the grid.
ϕ (i.e. $\hat{h}$, f, m_{fu} , m_j , ρ , T, μ_{eff})	NX*NY	storage is provided for boundary nodes as well as for the control cells.
p	(NX-2)*(NY-2)	storage is provided for internal cells only and not for boundary nodes.
p^*	NY	one-dimensional quantity.

The identification of a variable value at a particular nodal location is made by using a simple index determined from the IX, IY position of the variable in the two-dimensional field as follows:

<u>Variables</u>	<u>Fortran Name</u>	<u>Indexing</u>
ϕ (i.e. $\hat{h}$, f, m_{fu} , m_j , ρ , T, μ_{eff})	See previous page	$I=(IX-1)*NY+IY$
u	U(I)	$I=(IX-1)*NY+IY$
v	V(IV)	$IV=(IX-1)*NYM1+IY$
p	P(IP)	$IP=(IX-2)*NYM2+IY-1$
p^*	PP(IY)	IY

It should be noted that the convention employed for relating the referencing of the staggered velocity nodes to the main nodes is known as the 'L rule', and is shown below:



All of the variable arrays are equivalenced to the single one-dimensional array F. The size of the F array is equal to the sum of all of the variable arrays which are stored in F.

The identification of an element in the F-array is performed using I and an identifier IZERO(JPHI). IZERO(JPHI) indicates the last storage location in the (JPHI-1) th block of the F-array, e.g. EMU(I) in F(I) is:

$$F(I) = IZERO(JEMU) + IY + (IX - 1) * NY.$$

Other two-dimensional quantities stored in one-dimensional arrays are: VOL, AREAN, AEDDX, ANDDY. These are all geometrical quantities.

A.3 The problem-dependent subroutines, BLOCK DATA, MAIN, OUTPUT, PRINT, and BOUND

A.3.1 BLOCK DATA

This subroutine is used for the input of some data. It consists of nine chapters, the functions of which are explained by their titles; these will now be briefly described.

Chapter 1*. Preliminaries

In this chapter, identification and control parameters are defined. An inspection of the Glossary of Fortran variables in Appendix C, will reveal the function served by the parameters defined here.

Chapter 2. Grid and Geometry

In this chapter, the user must specify the number of transverse and longitudinal grid points and how they are distributed. Geometrical information relating to the dimensions of the combustor is also supplied here.

Chapter 3. Dependent variables

In this chapter, the indices (JU, JV, etc.) defining the location of a variable held in storage in the F-array and the indices (IDN, IDNO, etc.) defining the location of a species stored in the FS-array, are specified. The number and specification of the dependent variables solved for are also given here.

Chapter 4. Property Data

In this chapter, some of the properties of the fluids are specified. Some control parameters relating to properties and processes are also supplied here. Polynomial coefficients AC, AH, ASM, AS1 relating to chemical-equilibrium calculations

* The chapter numbers correspond to those of subroutine MAIN.

are defined here.

Chapter 5. Starting values

In this chapter, several arrays are initialised to zero; these are the default values. The flow rates, temperatures, fuel and oxygen concentrations of the two incoming streams and the inlet pressure are specified here.

Chapter 7. Boundary conditions

In this chapter, the parameters relating to heat transfer calculations (boundary conditions for the enthalpy equation) are specified.

Chapter 8. Advance

Here the maximum number of iterations to be performed at a given line is specified.

Chapter 11. Print

In this chapter, the parameters controlling the printout of the variables and residual errors are defined.

Chapter 12. Decide

In this chapter, the maximum number of iterative sweeps and the convergence criteria are specified.

A.3.2 Subroutine MAIN

Subroutine MAIN consists of 13 chapters, the functions of which are explained by their titles, and these will now be briefly described.

Chapter 0. Declarations

Here DIMENSIONS AND COMMON statements allocate storage and variable names.

Chapter 1. Preliminaries

Comment cards describing the special features of a particular run are placed in this chapter.

Chapter 2. Grid

In this chapter, a call is made to subroutine CONST(2) to calculate quantities related to the numbers of grid nodes in the x- and y-directions (NX and NY). Next subroutine GEOM is called to calculate grid related quantities.

Chapter 3. Variables

In this chapter comment cards are supplied to state the variables which appear in the differential equations and the auxiliary equations that are to be solved. Subroutine CONST(3) is called to calculate quantities related to the dependent variables.

Chapter 4. Property Data

In this chapter, subroutine REACT is called for the input for thermodynamic and reaction mechanism data. The laminar and turbulent Prandtl/Schmidt numbers of the various dependent variables, and the stoichiometric mixture fraction are also calculated here. The RHO (density) and EMU (viscosity) arrays are initialised with reference values.

Chapter 5. Starting Preparations

The function of this chapter is to:

- call subroutine CONST(5) for the calculation of certain reference indices;
- compute the properties in the inlet fuel and air streams;
- compute the normalising factors for residual errors;
- initialise dependent variable fields:
 - (a) $\tilde{h}$, u , f , m_{fu} , T , species mass fractions in DO-59 loop;
 - (b) NO_x - species in DO-580 and DO-582 loops;
 - (c) μ_{eff} in DO-597 loop;
 - (d) ρ in DO-593 loop;
 - (e) v in DO-590 loop (so as to be in continuity balance with the u specified above).

- call subroutine OUTPUT(1) to print out problem specification;
- call subroutine OUTPUT(2) to print out initial dependent variable fields;
- prepare for the start of a new iterative sweep.

Chapter 6. Step Control

In this chapter the DO-loop limits for the cross-stream TDMA (IYF and IYL) are set and certain indices related to the current IX value and to IYF and IYL are computed.

Chapter 7. Boundary conditions

The boundary condition information is supplied in chapter 7 of BLOCK DATA.

Chapter 8. Advance

This chapter results in the execution of a forward step and the computation of the dependent variables: u and v velocities, enthalpy, mass fraction of unburnt fuel, and mixture fraction.

The sequence of events in the execution of a forward step is:

- a call to COEFF(O) to obtain the diffusion fluxes;
- calls to FLOWM(1) and FLOWM(3) to obtain the convection fluxes;
- calls to COEFF(JU) and ADJUST(3) to perform an integral momentum balance for the current strip of cells (see section 3.3.5). This is performed only on the first iteration at the current line (i.e. when NTRAV=1).
- Finally the DO-800 loop incorporates call to COEFF(JPHI), once for every dependent variable JPHI which is to be solved. Also incorporated in this DO-loop are statements which ensure that when the enthalpy equation is being solved, the cross-stream TDMA extends through both the inner and outer ducts; for other variables, the extent of the field covered by the cross-stream TDMA is as illustrated in Fig. 5.

Chapter 9. Complete

In this chapter, variables which are not obtained directly by the line-by-line TDMA procedure are computed. This is achieved by calls to subroutine CHEM (only for INERT=2, reacting flows):

- (a) at ENTRY TEMP to compute the temperature;
- (b) at ENTRY DENS to compute the density;
- (c) at ENTRY EQUIL for chemical-equilibrium computations (only for IEQUIL=1);
- (d) at ENTRY KINE for chemical-kinetics computations (only for KNTCS=1 and ISWEEP>KSWEEP).

For non-reacting flows (INERT=1), control is transformed to statement number 905 and the temperature (if KSOLVE(JTEM). NE.0) is computed in the DO-930 loop. The computation of temperature is as per the discussion presented in Section 3.7.

Next the effective viscosity values are updated in the DO-940 loop. Finally, the influence coefficients DU used in the pressure-correction equation (Sec.3.3.4) are set to zero when dealing with the last column of cells. The reason for this is that the boundary velocities are specified and do not require to be corrected by the pressure-correction equation.

Chapter 10. Adjust

The purpose of this chapter is to perform sectional adjustments in order to achieve integral mass and momentum balances across a strip of cells and also to obtain local continuity balance.

Firstly, overall continuity across the strip is obtained by calls to subroutines FLOWM(2) and ADJUST(1).

Next, local continuity balance is obtained by calls to subroutines FLOWM(1), FLOWM(2), COEFF(JPP) and ADJUST(2); this step involves the solution of the pressure-correction equation.

Finally, subroutine ADJUST(3) is called to obtain integral momentum balance.

Chapter 11. Print

In this chapter, a reference pressure is subtracted from the pressure field to obtain the pressures relative to a selected reference point (IXPREF, IYPREF). Next subroutine BOUND is called, once for each dependent variable solved; this updates the values of the variables on the boundaries for printout purposes.

Chapter 12. Decide

In this chapter the following decisions are taken:

- (1) If the maximum sum of the residuals on the current line RSMAX is greater than the convergence criterion RSCHEK and if the number of iterations NTRAV on the line is less than the specified maximum value of NTDMA, the solution on the same line is repeated by transferring control to statement number 80. Otherwise step (ii) below is followed.
- (ii) A check is made to see if the sweep has been completed. If yes, then subroutine OUTPUT(3) is called for the printout of residual sources of the variables. If no, then control is transferred to statement 65 for the execution of the next forward step. Subroutine OUTPUT(2) is called for the printout of the field values of the variables every IPRINT sweeps; then step (iii) below is taken.
- (iii) Finally, if the largest residual source sum RSMAX in the field is greater than the convergence criterion CCHECK and if the number of sweeps performed ISWEEP is less than the maximum number specified LSWEEP, control is transferred to statement 50 for the start of a new sweep. Otherwise subroutine OUTPUT(2) is called for obtaining the final printout of the dependent variable fields.

A.3.3 Subroutine OUTPUT

Subroutine OUTPUT is divided into four chapters which are now briefly described:

Chapter 1. Preliminaries

This chapter provides by way of DATA statements, values for certain variables used during printout.

Chapter 2. Headings

This chapter is used to obtain some initial printout describing the problem and the input data. Chapters 1 and 2 are activated by CALL OUTPUT(1) from chapter 5 of subroutine MAIN.

Chapter 3. Field values

This chapter prints out the fields of each dependent and auxiliary variable solved for by calling subroutine PRINT. This chapter is activated by CALL OUTPUT(2) from chapter 12 of subroutine MAIN.

Chapter 4. Printout of residual sources and monitoring values

This chapter prints out the residuals of the finite-difference equations for each dependent variable solved and the variable values at the monitoring grid node (IXMON, IYMON). This chapter is activated by CALL OUTPUT(3) from chapter 12 of subroutine MAIN.

A.3.4 Subroutine PRINT

Subroutine PRINT is used to print the field values of the dependent variables. It is divided into three chapters which are described below.

Chapter 1. Preliminaries

In this chapter the appropriate DO-loop limits for the printout

of different variables are set. This is necessary, since as described in Section A.2.3, the storage arrangement is different for different variables.

Chapter 2. Print Titles of variables

As its name indicates, this chapter is used to print the titles of variables stored in the array TITLE.

Chapter 3. Print field values

Finally, in this chapter the field values of the dependent variables are printed.

Subroutine PRINT is called from Chapter 3 of subroutine OUTPUT once for every dependent variable solved and after every IPRINT number of iterative sweeps.

A.3.5 Subroutine BOUND

The function of this subroutine is to update the values of the dependent variables on the boundaries of the integration domain. This updating is a purely 'decorative' exercise and does not influence any computations. Examples of such updating are: setting the centreline value of a dependent variable equal to that at the neighbouring radial grid node; setting the exit plane values equal to those at the neighbouring axial grid node, etc.

Subroutine BOUND consists of a number of sections, one for each dependent variable. The appropriate section is accessed by means of IF-statements at the beginning of the subroutine. The coding is straightforward and easy to interpret with the aid of the comment cards provided.

Subroutine BOUND is called from Chapter 11 of subroutine MAIN, once for each dependent variable being solved.

A.4 The physical-model subroutines, SOURCE and WALL

These two subroutines incorporate the physical models describing the flow situation.

A.4.1 Subroutine SOURCE

The function of this subroutine is to compute the source terms of the dependent variables. It is divided into seven chapters described below. This subroutine is called from subroutine COEFF.

Chapter 1. Preliminaries

In this chapter, IF statements are provided for the transfer of control to any one of the succeeding chapters depending on the dependent variable currently being solved.

Chapter 2. Source terms for u

In this chapter the source terms of the u-momentum equation are computed. The calculation of the general source term as given in Table 1 of chapter 2 is incorporated in the DO-11 loop. For the particular case when both density and viscosity are uniform (as indicated by KRHOMU=0), certain terms are identically zero; the calculation of the source term is then simplified and this is included in the DO 13-loop.

Sources associated with inertial under-relaxation (Section 3.4.2) are also treated in the DO-11 loop.

Finally, at the end of this chapter, programming sequences are provided to include the shear stresses at the inner tube as sources in the u-momentum equation. This follows the discussion of Sections 4.1 and 4.2 and the programming is the Fortran equivalent of the formulae derived in Chapter 6 of Ref 7.

Chapter 3. Source terms for v

In this chapter the source terms of the v -momentum equation are computed. This chapter is similar to chapter 2.

Chapter 4. Source terms for $\tilde{h}$

In this chapter the source terms of the stagnation enthalpy equation are computed. Inspection of Table 1 of chapter 2 shows that no source terms are normally associated with this equation. The sources in this case are all associated with the heat transfer boundary conditions as discussed in Section 4.3.

Firstly, heat transfer at the inner tube wall is considered (Sec. 4.3.2). The convective and overall heat-transfer coefficients are computed here. Next axial conduction and wall-to-wall radiation fluxes are computed. These are incorporated into the SU-SP terms at the nodes IYWM1, IYW, IYWP1 as per equations (131) to (138).

After this, heat transfer at the outer duct wall is considered (Sec 4.3.3). The programming sequence is similar to that for the inner tube and involves a modification of the SU-SP terms at the nodes NY and NYM1.

Next heat transfer at the end wall is considered. In the DO-425 loop the heat transfer from the wall to the gas is included in the sources of the nodes adjacent to the wall (i.e. IX=NXM1). Finally, in the DO-435 loop the heat transfer to the end wall is considered. Here radial conduction, radiation to the surroundings and free and forced convection to the surroundings are all computed as per the discussion in Section 4.3.

Chapter 5. Source terms for mixture fraction

Inspection of Table 1 of chapter 2 shows that the mixture fraction equation has a zero source term. Consequently, the SU and SP arrays are simply set to zero in the DO-52 loop.

Chapter 6. Source terms for fuel

The computation of the fuel source term is done according to the linearised source-term expressions derived in Section 4.5 of Ref. 10. The programming sequence is contained in the DO- 62 loop and is similar to that provided in Ref. 10.

Chapter 7. Source terms for p'

The source term of the pressure-correction equation is the mass imbalance associated with the 'starred' velocity field (Section 3.3.4). It is therefore computed in the DO-92 loop by adding up the convective fluxes through the four faces of a finite-difference cell.

At the last column of cells ($IX=NXM1$), the set of equations defining the pressure-corrections is singular since the summation of the S_u -terms of equation (96) for this column is identically zero. This singularity is removed by setting the pressure correction at the IYL node to zero. This is done by the treatment: $SU(IYL)=0.0$, $SP(IYL)=-BIG$ (a large number). It can be seen from equation (73) that this SU-SP modification will result in a zero pressure-correction at the IYL node.

Finally, the outlet plane boundary condition of uniform pressure is imposed by ensuring the pressure-corrections are zero via the SU-SP modification described above.

A.4.2 Subroutine WALL

The function of this subroutine is the calculation of the quantities required for the modification of the finite-difference coefficients for the nodes adjacent to the duct wall.

On entry into this subroutine, certain indices are computed for use later in the subroutine. Control is then transferred to

statement number 10 if the variable in question is the u-velocity (JPHI=JU). Here some 'reference' values are chosen for density, viscosity, velocity and radius. These are chosen rather arbitrarily. Then if laminar flow is indicated either by KLT being equal to unity or the Reynolds number (based on the 'reference' values) being less than 132.25 ($\approx 11.5^2$), control is transferred to statement number 19. Here quantities related to laminar flow are computed. Otherwise the turbulent flow section is accessed. The programming sequence here is easy to interpret and is the Fortran equivalent of the formulae derived in chapter 6 of Ref. 7. (see also Section 4.1).

If the variable in question is the v-velocity, then control is transferred to statement number 200. This section is similar to the u-velocity section described above and involves the inclusion of the shear stresses at the end wall in the v-velocity equation.

Subroutine WALL is called from subroutine COEFF once for u-velocity, and once for v-velocity.

A.5 The chemical-model subroutines, CHEM, SPECE, and CALC

These subroutines incorporate the computations involved with the chemistry of the flow. The chemical-kinetics computations are mainly incorporated in subroutines SPECE and CALC which are simplified versions of those given in Ref. 3. These subroutines have been simplified from their original general version to make them more particular to the problem considered here.

A.5.1 Subroutine CHEM

This subroutine is divided into four chapters, each having its own ENTRY and RETURN statements.

Chapter 1. ENTRY TEMP

The function of this subprogram is to compute the temperature of the gas mixture for specified stagnation enthalpy and composition. The method described in Section 3.7 is followed. On entry into this subprogram indices NS1 and NS2 are set appropriate values depending on whether the chemical-kinetics solution is required (KNTCS=1) or not required (KNTCS=0).

The DO-115 loop spans all the internal cross-stream points. Firstly the mass fraction of unburnt fuel is restricted to be no greater than the mixture fraction. Next the concentrations of oxygen and products (considered as one species) are obtained; the concentration of nitrogen is obtained by a process of subtraction in the DO-105 loop. Finally, the DO-110 loop incorporates the Newton-Raphson iteration scheme for temperature. At each iteration the enthalpy (HMX) and the specific heat (CPMX) of the equilibrium-product-species are obtained using polynomial fits; thus the computation of each individual species-concentration is avoided. The number of iterations is restricted to NTMAX or less if the normalised change in temperature from one iteration to the next is less than EPST. Both NTMAX and EPST

are defined in Chapter 4 of BLOCK DATA.

Subprogram TEMP is called from subroutine MAIN (Chapter 9).

Chapter 2. ENTRY DENS

The function of this subprogram is to determine the density of the gas mixture. The density is computed in the DO-210 loop which spans all internal cross-stream points. In obtaining the mean molecular weight of the gas mixture, the contribution of the equilibrium-product-species is obtained by means of a polynomial involving temperature.

Subprogram DENS is called from subroutine MAIN (Chapter 9), when INERT equals 2 (reacting flows).

Chapter 3. ENTRY EQUIL

The function of this subprogram is to obtain the concentrations of the equilibrium-product-species. This is done by using polynomial expressions described in Section 3.5.4.

This subprogram is called from subroutine MAIN (Chapter 9), when INERT equals 2 (reacting flows), and IEQUIL equals unity.

Chapter 4. ENTRY KINE

This subprogram is used to obtain the concentrations of the NO_x-species by reference to kinetically-controlled reactions.

Firstly initial estimates for the concentrations of the NO_x-species are specified at the cross-stream plane being solved for and the one downstream of it. This is done by simply setting these values equal to those at the corresponding upstream grid node. This is done in the DO-482 loop which is accessed only during the first iterative sweep for the solution of the NO_x-species (i.e. ISWEEP. EQ. KSWEEP or (KSWEEP+1)); the chemical-kinetics solution is started after other variables have undergone KSWEEP number of iterative sweeps and have stabilized to a certain extent.

The DO-487 loop spans all the internal cross-stream points. In this loop the following operations are performed at each grid node:

- computation of the mole numbers of all the species and storing them in the S2-array (DO-486 loop);
- computation of the weighted averages of the mole numbers of the NO_x -species at the four neighbouring nodes and storing them in the S1-array (DO-488 loop) (this corresponds to σ_1^* of equation (121), Section 3.6.1);
- a call to subroutine SPECE to obtain the chemical-kinetics solution (i.e. mole numbers of the NO_x -species) for temperatures greater than 550°K ;
- conversion of the mole numbers to mass fractions (DO-489 and DO-490 loops);
- adjusting the mass fraction of nitrogen to ensure that all mass fractions add to unity (DO-493 loop).

It will also be noted that should a converged solution be not obtained from subroutine SPECE (as indicated by $\text{CONVG} = .\text{FALSE.}$) a warning message is printed out and the NO_x -species-concentrations set equal to the weighted averages of their concentrations at the four neighbouring nodes (DO-402 loop). This is also done for temperatures not greater than 550°K .

Subprogram KINE is called subroutine MAIN (Chapter 9) when $\text{ISWEEP} > \text{KSWEET}$ and $\text{KNTCS} = 1$.

A.5.2 Subroutine SPECE

The function of this subroutine is to control the Newton-Raphson iteration procedure for the solution of the chemical-kinetics equations as described in Section 3.6. This subroutine consists of five chapters.

In Chapter 1 the logarithms of the species mole-numbers are computed in the DO-10 loop. The sum of the species mole-numbers and its logarithm are also computed here. The size of the correction matrix, IMAT, is then specified.

In Chapter 2 the main iteration loop (DO-170) is started. The elements of the Newton-Raphson correction matrix are set up by a call to subroutine CALC. Subsequent statements in Chapter 2 involve the standard Gaussian pivotal elimination solution procedure for the correction matrix.

In Chapter 3 the under-relaxation parameter ETA is computed as described in Ref. 2.

In Chapter 4 the species mole numbers are corrected, the corrections being scaled by the factor ETA.

In Chapter 5 the convergence criterion is applied (Section 3.6.3). If all the species mole numbers have converged to within a user-specified tolerance limit EPSS, the variable CONVG is set equal to .TRUE., and iteration is stopped. Otherwise the same set of operations is repeated until convergence is achieved; the maximum number of iterations being restricted to ITMAX. Values of both ITMAX and EPSS are set in BLOCK DATA (Chapter 4).

Provision is made for printout of several quantities for diagnostic purposes at various stages of this subroutine. This printout is triggered by setting IDEBUG equal to one in Chapter 4 of BLOCK DATA.

Subroutine SPECE is called from subroutine CHEM (ENTRY KINE).

A.5.3 Subroutine CALC

The function of this subroutine is to construct the Newton-Raphson correction matrix for the solution of the chemical-kinetics equations as described in Section 3.6. This subroutine consists of three chapters.

In Chapter 1 all the elements of the correction matrix are initialised to zero. The mixture density is also computed.

In Chapter 2 the forward and reverse rates for each reaction are computed in the DO-100 loop. Only three different types of reactions have been considered:

MODE = 1 : $A + B \rightarrow C + D$
MODE = 2 : $AB + M \rightarrow A + B + M$
MODE = 3 : $A + B + M \rightarrow AB + M$

Relevant Fortran statements are provided to determine the reaction type and for MODES 2 and 3, control is transferred to statements 20 and 30 respectively. Subsequent statements compute the correction matrix elements as per the equations given in Section 3.6. All these operations are performed for each reaction in the DO-100 loop.

Chapter 3 completes the calculation of the matrix elements; the term $A_p \sigma_i$ of equation (121) is added to the diagonal elements and the term $A_p (\sigma_i - \sigma_i^*)$ of equation (121) is added to the last column of the correction matrix.

Subroutine CALC is called from Chapter 2 of subroutine SPECE.

A.6 The Computational Subroutines, COEFF, CONST, FLOWM, ADJUST, GEOM and TEST

A.6.1 Subroutine COEFF

This subroutine is used to set up the finite-difference coefficients and solve the finite-difference equations of the various dependent variables. It is divided into five chapters which are described below.

Chapter 1. Preliminaries

The upwind scheme of combining the diffusion and convection terms is defined here by means of an arithmetic statement function. Following this, are IF-statements which transfer control to the appropriate part of the subroutine depending on the variable being solved. Next the diffusion fluxes for the continuity cells on the current line and the one downstream (in the march direction) of it are computed in the DO-158 loop. The statements here are the Fortran equivalents of the equations given in Sec. 3.3.2(c). Care is taken to ensure that the diffusion terms on the boundaries are zero; the boundary effects being introduced through source terms later on.

Chapter 2. Coefficients for u-equation

In this chapter the finite-difference coefficients of the x-momentum equation are computed: (a) in the DO-26 loop when sweeping in the positive-x direction (INC=1); and (b) in the DO-27 loop when sweeping in the negative-x direction (INC=-1). The programming sequences here are simply the Fortran equivalents of the equations given in Section 3.3.3.

Next subroutine SOURCE(JU) is called to obtain the source terms and subroutine WALL to obtain the wall shear stresses. The TDMA coefficients are set up in the DO-290 loop and the back-substitution is done in the DO-292 loop. The residual errors are computed in the DO-291 loop, just before the u-velocities are updated by the

TDMA in the DO-292 loop.

Chapter 3. Coefficients for v-equation

In this chapter the finite-difference coefficients of the r-momentum equation are computed in the DO-36 loop. The coding is similar to that of chapter 2 above. Next subroutine SOURCE(JV) is called for the source terms and subroutine WALL for the wall shear stresses. The application of the TDMA is contained in the DO-390 and DO-392 loops and the residual-error calculation is contained in the DO-391 loop.

Chapter 4. Coefficients for pressure-correction equation

In this chapter the coefficients of the pressure-correction equation are calculated (Sec. 3.3.4) in the DO-46 loop. Here it is ensured that when sweeping in the positive-x direction (INC=1), the west-coefficient AW is zero; since in this case only the east-side u-velocities are affected by the pressure-correction equation. Similarly, when sweeping in the negative-x direction (INC=-1), the east-coefficient AE is set to zero.

Next subroutine SOURCE(JPP) is called to obtain the error mass-source associated with the 'starred' velocity field. Finally the DO-490 and DO-492 loops contain a standard application of the TDMA to obtain the pressure-corrections.

Chapter 5. Phi equation

In this chapter, the finite-difference coefficients of the general ϕ equation are computed in the DO-56 loop (Sec. 3.3.2(c)). Next subroutine SOURCE(JPHI) is called to obtain the source terms. The application of the TDMA is contained in the DO-590 and DO-592 loops and the residual-error calculation in the DO-591 loop.

A.6.2 Subroutine CONST

Subroutine CONST sets constants for use within the program. These are as follows:

- constants related to the total number of x and y grid points;
- constants related to the storage of variables;
- constants setting special points within the field to give pressure reference and monitoring locations.

A.6.3 Subroutine FLOWM

This subroutine is used for the calculation of the convection fluxes for the continuity cells on the current line and the one downstream (in the march direction) of it. The calculation is incorporated in several DO-loops in which the fluxes for the different faces are computed. The reason for splitting the computation into different DO-loops is that on any call to this subroutine only the fluxes which are required on that call may be calculated by accessing the appropriate DO-loop. It will also be noticed that the upwinding of density (e.g. equation (62)) in obtaining the fluxes is performed here.

A.6.4 Subroutine ADJUST

This subroutine is used to perform section-wise mass and momentum balance and cell-wise continuity balance. It is divided into three chapters which are described below.

Chapter 1. Overall-continuity correction

In this chapter section-wise mass balance is achieved. First the integral mass flow rate associated with the 'starred' velocity field is obtained: (a) in the DO-100 loop when sweeping in the positive-x direction (INC=1); and (b) in the DO-1011 loop when

sweeping in the negative-x direction ($INC=-1$). Then the u-velocities are incremented by a uniform amount DELU in the DO-101 loop to achieve section-wise mass balance.

Chapter 2. Cell-wise continuity correction

In this chapter cell-wise continuity is obtained by correcting the 'starred' velocities u^* and v^* as per equations (88) and (89) of Section 3.3.4. The pressure is also augmented by an amount equal to the pressure-correction times an under-relaxation factor (as in equation (105) of Section 3.4.2); however the mean pressure level is kept the same so as not to disturb overall momentum balance.

Chapter 3. Overall-momentum correction - SNIP

This chapter incorporates the coding sequences for achieving section-wise momentum balance. This follows the discussion of Section 3.3.5. The average correction to the pressure field ($\Delta \bar{p}$ of equation (97)) is obtained from the DO-302 loop. This $\Delta \bar{p}$ is added to the pressures downstream of the current line in the DO-315, DO-306, DO-308 and DO-309 loops, each of which deals with one particular part of the combustor.

A.6.5 Subroutine GEOM

This subroutine is used to calculate quantities associated with the finite-difference grid. It is divided into three chapters which are described below.

Chapter 1. Radii

In this chapter the radii of the grid nodes are obtained. These are simply equal to the y-coordinates specified in Chapter 2 of BLOCK DATA.

Chapter 2. Cell-node distances

In this chapter the internodal distances DXG (DO-30 loop) and DYG (DO-31 loop) and their reciprocals RDXG and RDYG are calculated. The locations of the u-nodes, XU, are obtained in the DO-32 loop. The distances between the u-nodes, DXU (and their reciprocals, RDXU) are then calculated in the DO-33 loop. Next, the v-node locations are calculated in the DO-34 loop and the distances between these nodes are obtained in the DO-35 loop.

Chapter 3. Cell dimensions

In this chapter the following quantities are calculated:

- lengths of the main cells, SXG, SYG;
- lengths of the u-cells, SXU;
- lengths of the v-cells, SYV;
- the north and east face areas of the main cells, AREAN and AREAE;
- the north and east face areas divided by the internodal distances, ANDDY and AEDDX;
- the volume of each main cell, VOL.

A.6.6 Subroutine TEST

The function of this subroutine is to print information for program testing and debugging. The level of diagnostic detail may be prescribed using the index KTEST (defined in BLOCK DATA) as follows:

KTEST=1 : prints out the geometrical quantities; gives the variable-information; and prints the initial values in the field. This is contained in Chapter 1 of this subroutine.

KTEST=2 : prints out the just calculated values of the dependent variables; their residual sources; the pressure-correction

quantities, as well as all quantities for KTEST=1. This is contained in Chapter 2 of this subroutine.

KTEST=3 : prints out the finite-difference coefficients; the convection and diffusion fluxes, as well as all quantities for KTEST=1 and 2. This is contained in Chapter 3 of this subroutine.

A.7 The Thermochemical property subroutines, REACT and HCPS

These subroutines are concerned with the input and calculation of certain thermodynamic quantities. They have been adapted from Ref.3 with some changes.

A.7.1 Subroutine REACT

The function of this subroutine is to read, store and process thermochemical data. This subroutine is divided into 4 chapters.

In Chapter 1 certain quantities are defined through data statements. Then follow statements which cause control to be transferred to the appropriate chapter. This depends on which of the words ELEMENTS, THERMO, MECHANISM, or a blank card is encountered in the data deck. Data cards must be in this order, since element data is needed to process thermodynamic data, and thermodynamic data for kinetic-mechanism data. If the chemical-kinetics solution is not required (i.e. KNTCS=0), the kinetic-mechanism data is not read.

Chapter 2 deals with element data. Here one data card is read for each element considered. The contents and format of each data card are given in Table A.1. The total number of elements is designated by NLM.

Chapter 3 deals with thermochemical data. Entry into Chapter 3 occurs after completion of Chapter 2 and via statement number 5. Four data cards are read for each chemical species considered. The contents and format of each data card are given in Table A.2. After the data cards for each species are read, its molecular weight is computed in the DO-24 loop. The total number of species is designated by NS.

The polynomial coefficients $Z(I,J,K)$ for the thermodynamic

TABLE A.1
ELEMENT DATA CARDS

Order of data cards	Contents	Format	Card Columns
First	ELEMENTS	3A4	1 to 8
Any order	One card for each element present in the system. Each card contains: (i) Atomic symbol of element. (ii) Atomic weight of element. (iii) Valence or oxidation state of the element (positive, negative, or zero).	A2 F10.6 F10.6	1 to 2 8 to 17 18 to 27
Last	Blank card.	-	-

TABLE A.2
THERMOCHEMICAL DATA CARDS

Order of data cards	Contents	Format	Card Columns
First	THERMO	3A4	1 to 6
Any order	A set of four data cards for each species considered. The cards in sequence and contain: (1)(a) Molecular symbol or name of species. (b) Date. (c) Atomic symbols & formula (d) Phase (gas only, letter G). (e) Temperature range, degrees K. (f) Card number. (2)(a) Coefficients Z_i ($i=1,5$) for upper temperature range. (b) Card number. (3)(a) Coefficients Z_6 and Z_7 for upper temperature range, and Z_1, Z_2, and Z_3 for the lower range. (b) Card number. (4)(a) Coefficients Z_i ($i=4,7$) for the lower temperature range. (b) Card number	3A4 2A3 4(A2,F3.0) A1 2F10.3 I15 5E15.8 I5 5E15.8 I5 4E15.8 I20 -	1 to 12 19 to 24 25 to 44 45 46 to 65 80 1 to 75 80 1 to 75 80 1 to 60 80 -
Last	Blank Card.	-	-

TABLE A.3
REACTION MECHANISM DATA CARDS

Order of data card	Contents	Format	Card Columns
First	MECHANISM	3A4	1 to 9
Any order	One data card for each forward (or optionally, reverse) reaction considered. Each card contains: (i) Molecular symbols of upto three reactant species*. (ii) Molecular symbols of upto three product species*. (iii) Exponent B_j^{**} . (iv) Exponent N_j^{**} . (v) Activation temperature T_{actj}^{**} . (vi)(a) For forward reactions, date or comments. (b) For reverse reactions, REVERSE ⁺ .	 3(2A4) 3(2A4) F8.3 F8.3 F8.3 2A4 2A4	 1 to 24 25 to 48 49 to 56 57 to 64 65 to 72 73 to 80 73 to 79
Last	Blank card.	-	-

*Molecular symbols must be identical to those used in thermochemical data cards.

**Quantities as defined in:

$$k_{fj} = 10^{B_j} T^{N_j} \exp(-T_{actj}/T) \text{ with units}$$

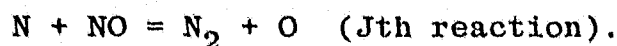
$m^3/$ (kg-mole-sec) for bimolecular reactions,
and $m^6/$ (kg-mole)²sec for termolecular reactions.

⁺When REVERSE is specified, Columns 1 to 48 are ignored. The data card with reverse rate data must follow immediately the card with the corresponding forward rate data.

properties are divided by the respective molecular weights in the DO-27 loop. Since the present program performs computations with species mass fractions rather than mole numbers, the coefficients will be required in this modified form.

Chapter 4 deals with kinetic-mechanism data. Entry into Chapter 4 occurs after completion of Chapter 3 and via statement number 5. One data card is read for each reaction considered. The contents and format of each data card are given in Table A.3. In statements 33 to 38, the numbers to be stored in the ID (N,J) array are calculated. ID (N,J) is equal to the species index number I (I=1,NS) of the Nth (N=1,4) species which appears in the Jth (J=1,JJ) reaction.

Thus for the reaction



ID (1,J)=IDN, ID(2,J)=IDNO, ID(3,J)=IDN2, ID(4,J)=IDO. IDN, IDNO, etc., which identify the different species are defined in Chapter 3 of subroutine BLOCK DATA.

The rest of Chapter 4 is devoted to the computation of the reverse reaction rates, for each forward reaction rate just read in. The reverse reaction constant is obtained from the ratio of the forward reaction rate constant and the equilibrium constant. This is done for fifteen temperatures between 1000°K and 3000°K and the reverse rate parameters are obtained by a least-square linear regression analysis. Details of this computational procedure are given in Ref 3.

If however, the reverse rate data is also supplied on a data card which is subsequently read, the calculated reverse rate parameters are overwritten. This is indicated by the statement just preceding statement number 32.

Subroutine REACT is called from Chapter 4 of subroutine MAIN.

A.7.2 Subroutine HCPS

The function of this subroutine is to compute certain thermodynamic quantities (See Section 5.2).

On entry into this subroutine a check is made to see if the temperature is less than 1000°K ; this is to decide whether to use the coefficients for the lower (temperature $<1000^{\circ}\text{K}$) or the higher (temperature $>1000^{\circ}\text{K}$) temperature range. Depending on the value assigned to the variable IHCPs, the following properties are computed:

- (i) IHCPs = 1 : The non-dimensional species enthalpy $\text{HO}(\text{I})$ and the non-dimensional mixture enthalpy HSUM are computed in the DO-5 loop.
- (ii) IHCPs = 2 : The non-dimensional species enthalpy $\text{HO}(\text{I})$, the non-dimensional mixture enthalpy HSUM and the non-dimensional mixture specific heat CPSUM are computed in the DO-10 loop.
- (iii) IHCPs = 3 : The non-dimensional species enthalpy $\text{HO}(\text{I})$, and the non-dimensional species entropy $\text{SO}(\text{I})$ at one-atmosphere are computed in the DO-20 loop.

Subroutine HCPS is called from:

- (a) Subroutine REACT, Chapter 4, during the computation of reverse reaction rate parameters, with $\text{IHCPs}=3$;

(b) Subroutine MAIN:

- Chapter 5, to obtain inlet enthalpies of the fuel and air streams, with IHCPS=1;
- Chapter 9, to obtain the mixture enthalpy and specific heat, with IHCPS=2;

(c) Subroutine CHEM:

- Chapter 1 (ENTRY TEMP), to obtain the mixture enthalpy and specific heat, with IHCPS=2.

APPENDIX B

LISTING OF THE NASCO II COMPUTER PROGRAM

BLOCK DATA	BD000010
COMMON/COMA/ U(480),V(475),H(500),FM(500),FUE(500),FS(500,15),	BD000020
1 PP(20),TEM(500),P(414),RHO(500),EMU(500),	BD000030
1 DXG(25),DXU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),	BD000040
2 STORE(25),SXG(25),SXU(25),X(25),XU(25),	BD000050
3 A(20),AF(20),AH(20),AREAE(20),AS(20),ASNIP(20),AW(20),B(20),	BD000060
4 USHIP(20),C(20),DSNIP(20),DIFE(20),DIFEE(20),DIFN(20),	BD000070
5 DIFHF(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),	BD000080
6 FLOWE(20),FLOWEE(20),FLOWN(20),FLOWHE(20),FLOWW(20),R(20),	BD000090
7 RUYG(20),RUYV(20),RSYG(20),RSYV(20),RV(20),RVCB(20),RVSQ(20),	BD000100
8 SP(20),SU(20),SYG(20),SYV(20),Y(20),YV(20),AEDUX(500),	BD000110
9 ANDDY(500),AREAN(500),VOL(500),	BD000120
X ARSL(25,25),PREFF(25),PRL(25),PRT(25),RSLINE(25,25),	BD000130
1 IEW(25),ILAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),	BD000140
2 RSRCE(25),RSSUM(25),TITLE(25)	BD000150
DIMENSION DIFNW(20),DIFWW(20),F(11889),FLOWNW(20),FLOWWW(20)	BD000160
EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),	BD000170
1 FLOWFE(1)),(DIFNW(1),DIFNE(1)),(DIFWW(1),DIFEE(1))	BD000180
COMMON/COMB/	BD000190
1 AK,ARRCON,BIG,CHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,	BD000200
2 EPST,CORAT,EWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,	BD000210
3 FSTOIM,FUB,FUC,HFU,HW,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,	BD000220
4 ISWEEP,IX,IXMON,IXPREF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,	BD000230
5 IX1NY1,IX2NYU,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,	BD000240
6 IYPREF,IYW,IYWM1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,	BD000250
7 JS1,JS2,JTEM,JU,JV,KASE,KINPRI,KLT,KRAD,KRIHOMU,KSWEET,KTEST,	BD000260
8 LABPHI,LSWEEP,MSOLVE,NTDMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,	BD000270
9 NXM2,NXYG,NXYP,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OXB,OXE,PJAY,	BD000280
X PREEXP,PRESS,RELAXP,RF,RFSTM,RSCHK,RSMAX,R11,R10,R21,R20,	BD000290
1 SIOICH,TR,IC,TINY,TMAX,TMIN,UB,UC,WMIX	BD000300
LOGICAL CONVG	BD000310
COMMON /INDEX/ IDCO,IDCO2>IDF,IDH,IOH2,IOH20,IDO,IDOH,IDO2,IDN,	BD000320
1 IDNO,IOND2,IDN2,IDN20,IEQUIL,INCPS,IPR,JJ,KNTCS,NA,NLM,	BD000330
2 NS,HSE1,HSE2,NSK,NSM,NS1,NS2,IO(4,15)	BD000340
3/PARAMS/ CONVG,EMV,EPSS,GASCON,IDEBUG,ITMAX,PA,SM,TINYK,TK,TLN,TNY	BD000350
5/SPLCES/ASUB(20,3),CPSUM,HSUM,H0(14),SMW(14),S0(14),S1(14),	BD000360
6 S2(14),Z(2,7,14)	BD000370
7/CEQUIL/AC1,AC2,AC3,AC4,AH1,AH2,AH3,AH4,ASM1,ASM2,ASM3,ASM4,	BD000380
8 AS1(4,7,2),HDIIV,HMAX,HMIN,PEXP(7)	BD000390
9/REACTS/BX(15),BX2(15),TACT(15),TACT2(15),TEN(15),TEN2(15)	BD000400
COMMON/INTR/ ALNR11,ALNR10,ALNR21,ALNR20,COND,EL3,	BD000410
1 LMIS10,LMIS21,EMIS20,EMISX1,EMISX0,REMI,RHOINF,	BD000420
1 SIGMA,STX1,STX0,S111,ST10,ST21,ST20,TINF,UINF,VINF,WARLA	BD000430
C-----	BD000440
CHAPTER 1 1 1 1 1 1 1 1 PRELIMINARIES 1 1 1 1 1 1 1 1	BD000450
C-----	BD000460
DATA TINYK,INY/1.0E-20,-46.0517/	BD000470
DATA BIG,TINY/1.0E15,1.0E-10/	BD000480
DATA KTEST/0/	BD000490
DATA KASE/1/	BD000500
C-----	BD000510
	BD000520

2	-2.474E+01, 5.841E+01, -6.959E+01, 2.931E+01,	BD001050
3	-1.640E+01, 3.880E+01, -3.982E+01, 1.668E+01,	BD001060
4	-8.100E-01, 1.802E-01, -6.237E-01, 2.417E-01,	BD001070
5	-2.056E+01, 5.916E+01, -7.200E+01, 3.053E+01,	BD001080
6	-1.209E+01, 3.615E+01, -4.415E+01, 1.871E+01/	BD001090
	DATA PEXP/-0.5,0.0,-0.75,-0.5,0.0,-0.5,-0.25/	BD001100
	DATA GASCON/8314.4/	BD001110
	DATA TMIN,TMAX/200.0,4000.0/	BD001120
	DATA STUICH,ARRCON,PREEXP/4.0,18000.0,0.01/	BD001130
	DATA HFU,CMIX,WMIX/4.0E7,1100.0,29.0/	BD001140
	DATA EMUREF/1.8E-5/	BD001150
	DATA PRL,PRI/2*1.0,23*0.7,2*1.0,23*0.86/	BD001160
	DATA AK,EWALL/0.435,9.0/	BD001170
	DATA KLT/2/	BD001180
	DATA INERT/2/	BD001190
C-----		BD001200
CHAPTER 5 5 5 5 5 5 5 5	STARTING VALUES 5 5 5 5 5 5 5	BD001210
C-----		BD001220
	DATA ISWEEP/0/	BD001230
	DATA ARSL/625*0.0/	BD001240
	DATA RSLINE/625*0.0/	BD001250
	DATA IXMON,IYMON/3,3/	BD001260
	DATA IXPREF,IYPREF/2,2/	BD001270
	DATA F,DV/11889*0.0,20*0.0/	BD001280
	DATA DIFE,DIFEF,DIFH,DIFHE,DIFW/100*0.0/	BD001290
	DATA FLOWE,FLOWEL,FLOWN,FLOWNE,FLOWW/100*0.0/	BD001300
	DATA PRESS/2.0E5/	BD001310
	DATA EMF,EMA/1.4E-5,3.6E-4/	BD001320
C-----	TWO STREAMS ENTERING - STREAM 8 IS PURE FUEL, AND STREAM	BD001330
C	C IS AIR.	BD001340
	DATA TB,TC/275.0,275.0/	BD001350
	DATA FUB,FUC/1.0,0.0/;UXB,UXC/0.0,0.232/	BD001360
C-----		BD001370
CHAPTER 7 7 7 7 7 7 7 7	BOUNDARY CONDITIONS 7 7 7 7 7 7 7	BD001380
C-----		BD001390
	DATA COND/41.84/,SIGMA/5.67E-8/,	BD001400
	1 SIXI,SIXO/2*0.003/,SI11,SI10/2*0.003/,SI21,SI20/2*0.003/,	BD001410
	2 UIHF/1./,VINF/1./,IINF/300.0/,RHOINF/1.0/	BD001420
	3,EMIS10,EMIS21,EMIS20,EMISX1,EMISX0/5*0.05/	BD001430
C-----		BD001440
CHAPTER 8 8 8 8 8 8 8 8	ADVANCE 8 8 8 8 8 8 8 8	BD001450
C-----		BD001460
	DATA NTDMA/ 3/	BD001470
C-----		BD001480
CHAPTER 11 11 11 11 11 11 11 11	PRINI 11 11 11 11 11 11 11	BD001490
C-----		BD001500
	DATA KINPRI/1/	BD001510
	DATA NUNCOL/10/	BD001520
	DATA IPLRS,IPRINT/50,200/	BD001530
C-----		BD001540
CHAPTER 12 12 12 12 12 12 12 12	DECIDE 12 12 12 12 12 12 12	BD001550
C-----		BD001560

DATA LSWEET/150/
DATA HSCHEK, CCHILCK/0.01, 0.005/
END

80001570
80001580
80001590

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CALL CONST(5)	MA001050
LI 3=R20-R21	MA001060
R1 R1=1.0/EMIS21-1.0	MA001070
R2M=0.5*(R20+R21)	MA001080
WAREA=P2M*(R20-R21)	MA001090
AL NR11=ALOG(R(1YW)/R11)	MA001100
AL NR10=ALOG(R10/R(1YW))	MA001110
AL NR21=ALOG(R2M/R21)	MA001120
AL NR20=ALOG(R20/R2M)	MA001130
C	MA001140
PIGSCN=PRESS/GASCON	MA001150
PEB=1.0-FUB-UXB	MA001160
PRC=1.0-FUC-OXC	MA001170
WB=OXB/SMW(1002)+FUB/SMW(10F)+PRB/SMW(10N2)	MA001180
WC=OXC/SMW(1002)+FUC/SMW(10F)+PRC/SMW(10N2)	MA001190
RHOB=PDGSCN/(WB*TB)	MA001200
RHOC=PDGSCN/(WC*TC)	MA001210
FLOB=EM/6.2831853	MA001220
FLOC=EM/6.2831853	MA001230
FLOWIN=FLOB+FLOC	MA001240
INCP5=1	MA001250
HS1=1000	MA001260
HS2=1000	MA001270
TH=TC	MA001280
S2(1002)=PRB	MA001290
S2(10F)=FUB	MA001300
S2(1002)=OXC	MA001310
CALL HCP5	MA001320
ENTHB=HSUN*GASCON*TB	MA001330
TH=TC	MA001340
S2(10N2)=PRC	MA001350
S2(10F)=FUC	MA001360
S2(1002)=OXC	MA001370
CALL HCP5	MA001380
ENTHC=HSUN*GASCON*TC	MA001390
UC=PIGSCN/(0.5*RHOC*(R11+RF)*(R11-RF))	MA001400
UC=FLOB/(0.5*RHOB*RF**2)	MA001410
IYWI=IYW+1	MA001420
IYWI=IYW-1	MA001430
C ----- NORMALISING FACTORS.	MA001440
RSREF(JU)=FLOWIN*UC	MA001450
RSREF(JV)=RSREF(JU)	MA001460
RSREF(JU)=ABS(ENTHB*FLOB+ENTHC*FLOC)	MA001470
RSREF(JFH)=FLOWIN	MA001480
RSREF(JFUF)=FLOWIN	MA001490
RSREF(JFP)=FLOWIN	MA001500
C----- INITIALISE DEPENDENT VARIABLE FIELDS	MA001510
HOUT=(ENTHB*FLOB+ENTHC*FLOC)/FLOWIN	MA001520
FOUT=(FUB+FLOB+FUC*FLOC)/FLOWIN	MA001530
OXCOUT=(OXC*FLOB+OXC*FLOC)/FLOWIN	MA001540
EL2OUT=(PRB*FLOB+PRC*FLOC)/FLOWIN	MA001550
FUBRIT=AMAX1(TINY,(FOUT-FSTOIC)*RESTM)	MA001560

```

PROUT=(FOUT-FUBRNT)*(1.0+STOIGH)
OXBRT=ANAXI(TINY,(1.0-FOUT/FSTOIC)*OXC)
TBRNT=TC+OFU*(FOUT-FUBRNT)/CMIX
RHOBT=FUBSCN+NFIX/TBRNT
UOUT=FLOWIN/(0.5*RHOBT*(R21+R10)*(R21-R10))
DO 52 IX=1,NXM
  IF(IY.LI.IYFUL) GO TO 51
  IF(IY.LI.IYH) GO TO 53
  IF(IY.GI.IYH) GO TO 55
  DO 57 I=1,NXM
    I=IY+(IX-1)*NY
    H(I)=TC
57  TLM(I)=TC
    GO TO 52
51  DO 52 IX=1,NXM
    I=IY+(IX-1)*NY
    U(I)=UB
    H(I)=ENHHR
    FFI(I)=FUB
    FGE(I)=FUB
    TLM(I)=TB
    FS(I,1002)=PRB
    FS(I,100)=FUB
52  FS(I,1002)=OXR
    GO TO 52
53  DO 54 IX=1,NXM
    I=IY+(IX-1)*NY
    U(I)=UC
    H(I)=ENHHC
    FFI(I)=FUC
    FGE(I)=FUC
    TLM(I)=TC
    FS(I,1002)=PRC
    FS(I,100)=FUC
54  FS(I,1002)=OXC
    GO TO 52
55  DO 56 IX=1,NXM
    I=IY+(IX-1)*NY
    U(I)=UOUT
    H(I)=HOBT
    FFI(I)=FOUT
    FGE(I)=FUBRNT
    TLM(I)=TBRNT
    FS(I,100)=PROUT
    FS(I,1002)=LN2OUT
    FS(I,100)=FUBRNT
    FS(I,1002)=OXBRT
    IF(IY.HI.IY) GO TO 56
    U(I)=A.1
    H(I)=TC
56  CONTINUE
    IYWP=IYWI

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MA001570
 MA001580
 MA001590
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 MA001920
 MA001930
 MA001940
 MA001950
 MA001960
 MA001970
 MA001980
 MA001990
 MA002000
 MA002010
 MA002020
 MA002030
 MA002040
 MA002050
 MA002060
 MA002070
 MA002080


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      DO 560 IX=IXWP1,IXM1
      I=IY+(IX-1)*NY
      U(I)=UOUT
      H(I)=HOUT
      F(I)=FOUT
      FUE(I)=FOUT
      T(I)=TC
      FS(I,1002)=1.0-FOUT-0XOUT
      FS(I,1001)=FOUT
      FS(I,1002)=0XOUT
      IF (IY.NE.0Y) GO TO 560
      U(I)=0.0
      H(I)=TC
560 CONTINUE
      58 I=IY+IX*2+NY
      U(I)=0.0
59 CONTINUE
      IX1NY=IXM1+NY
      DO 581 IY=1,NY
      I=IY+IX1NY
      IX=I-NY
      TLM(I)=TH
      581 H(I)=TE(I)
C-----INITIALIZE DOX-SPECIES ARRAYS.
      DO 580 IX=2,3
      IX1NY=(IX-1)*NY
      DO 580 IY=1,1YDM1
      I=IY+IX1NY
      FS(I,1001)=1.0E-20
      FS(I,1000)=1.0E-15
      FS(I,1002)=1.0E-20
580 FS(I,1002)=1.0E-20
      IX1NY=(IX-1)*NY
      DO 582 IY=IYWP1,NY
      I=IY+IX1NY
      FS(I,1001)=1.0E-20
      FS(I,1000)=1.0E-15
      FS(I,1002)=1.0E-20
582 FS(I,1002)=1.0E-20
C
      IF (RESOLVE(JERM).EQ.0) GO TO 592
      LOUT=0.06+(FLOH+FLOC)/R11
      DO 597 IX=1,NX
      IX1NY=(IX-1)*NY
      DO 597 IY=1,NY
      I=IY+IX1NY
      CFI(I)=LOUT
597 CONTINUE
C
      592 IF (RESOLVE(JRMH).EQ.0) GO TO 595
      DO 593 IX=1,IXM1
      IX1NY=(IX-1)*NY

```

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MA002090
MA002100
MA002110
MA002120
MA002130
MA002140
MA002150
MA002160
MA002170
MA002180
MA002190
MA002200
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MA002220
MA002230
MA002240
MA002250
MA002260
MA002270
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MA002600

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      DO 503 IY=1,NYM1
      I=IY+IX1NY
      FPR=1.0-(FS(I,IOF)-FS(1,IOO2))
      VPIX=FS(I,IOF)/SMW(IOF)+FS(1,IOO2)/SMW(IOO2)+FPR/SMW(ION2)
503 RHO(I)=DGSCN/(VPIX*LEN(I))
C
505 DO 509 IX=2,IX1-1
      IXP1=IX-1
      IY1NY=IYM1+NY
      IY1NY1=IX1-1+NYM1
      DO 508 IY=2,NYM2
      I=IY+IX1NY
      IV=IY+IX1NY1
      ISV=IV-1
      IS=I-1
      Iu=I-NY
508 V(IV)=(V(TSV)*RHO(IS)*AREAN(IS)+AREAF(IY)*(U(IW)*RHO(IW)
      1-U(I)*RHO(I)))/(RHO(I)*AREAN(I))
C
      CALL OUTPUT(1)
C----- PRINT OUT STARTING VALUES
      IF (KINPRI.GT.0) CALL OUTPUT(2)
C
C***** NEW SLEEP STARTS HERE *****
C
50 ISWEEP=IS,LFP1)
      IF (MOD(ISWEEP,2).EQ.0) GO TO 500
      INC=1
      IX=1
      GO TO 501
500 INC=-1
      IX=NX
501 DO 510 J=1,JPP
510 RSSUP(J)=0.0
C-----
CHAPTER 6 6 6 6 6 6 6 STEP CONTROL 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
C-----
C***** NEW LINE STARTS HERE *****
C
65 IX=IX+INC
      IXU=IX
      IF (INC.EQ.-1) IXU=IX-1
C
      IF (IX.LE.IXW) GO TO 6000
      IYF=2
      IYL=NYM1
      GO TO 6002
6000 IF (INC.EQ.1) GO TO 6001
      IYF=IYMF1
      IYL=NYM1
      GO TO 6002
6001 IYF=2

```

[illegible]

IF (KTEST.GT.1) CALL TEST(24)	MA003650
801 ISNIP=1	MA003660
DO 800 JPHI=1,NSOLVE	MA003670
IF (KSOLVE(JPHI).EQ.0) GO TO 800	MA003680
IF (JPHI.EQ.00.AND.(IXU.GE.NXM1.OR.IXU.FO.1)) GO TO 800	MA003690
IYFSAV=IYF	MA003700
IYLSAV=IYL	MA003710
IF (JPHI.EQ.00) GO TO 802	MA003720
IF (IX.EQ.0X) GO TO 800	MA003730
GO TO 805	MA003740
802 IYF=0	MA003750
IYL=NY	MA003760
IYFM1=IYF-1	MA003770
IYLM1=IYL-1	MA003780
IYLP1=IYL+1	MA003790
803 LABPHI=JPHI	MA003800
CALL COLFI (JPHI)	MA003810
	MA003820
IF (KTEST.GT.1) CALL TEST(21)	MA003830
IYF=IYFSAV	MA003840
IYL=IYLSAV	MA003850
IYFM1=IYF-1	MA003860
IYLM1=IYL-1	MA003870
IYLP1=IYL+1	MA003880
800 CONTINUE	MA003890
CHAPTER 9 9 9 9 9 COMPLETE 9 9 9 9 9 9 9 9	MA003900
IF (INERT.EQ.1) GO TO 905	MA003910
CALL TEMP(KGOTO)	MA003920
IF (IX.EQ.0X) GO TO 1250	MA003930
CALL DENS(KGOTO)	MA003940
IF (IFEUIL.EQ.1) CALL EQUIL(KGOTO)	MA003950
IF (KITCH.FO.1.AND.ISWEEP.GE.KSWEEP) CALL KINE(KGOTO)	MA003960
GO TO 935	MA003970
905 IF (KSOLVE(JTEM).EQ.0) GO TO 935	MA003980
PLGSC4=PRESS/GASCON	MA003990
INCPS=2	MA004000
NS1=1002	MA004010
NS2=1002	MA004020
DO 940 IY=IYF,IYL	MA004030
I=IY+IXINX	MA004040
FUE(I)=FM(1)	MA004050
FS(1,ID02)=0XC*(1.0-FM(1))	MA004060
FS(1,101)=FUL(1)	MA004070
FS(1,ID02)=1.0-FUE(I)-FS(1,ID02)	MA004080
TR=TEM(1)	MA004090
ENTH=H(1)/GASCON	MA004100
DO 910 IS=NS1,NS2	MA004110
910 S2(IS)=FS(1,IS)	MA004120
DO 915 JT=1,ETMAX	MA004130
CALL INCPS	MA004140
DTEMP=(ENTH/TK-NSUM)/CPSUM	MA004150
	MA004160

T=ADINI(TMAX,TK*(1.0+DTEMP))	MA004170
TK=ADAX1(TNII,TK)	MA004180
IF (ABS(DTEMP).LE.LPST) GO TO 925	MA004190
915 CONTINUE	MA004200
WRITE(6,920) IX,IY,NTMAX,TK,DTEMP	MA004210
920 FORMAT(1H0,10(1H-),2X,31HPOOR CONVERGENCE OF TEMPERATURE/13X,	MA004220
1 7HAT IY =,13,10H, AND IY =,13/13X,22HNUMBER OF ITERATIONS =,13/	MA004230
2 13X,13,TEMPERATURE =,1PE15.6/13X,7HNTMP =,1PE15.6/13X,	MA004240
3 18H***ATN PROGRAM***//)	MA004250
925 TLM(1)=TK	MA004260
VMIX=FUE(1)/SMW(1DF)+FS(I,ID02)/SMW(ID02)+FS(I,IDN2)/SMW(IDN2)	MA004270
930 RHO(1)=FDSCLN/(TK*VMIX)	MA004280
C	MA004290
935 IF (RSOLVE(JEMU).EQ.0) GO TO 945	MA004300
DO 949 IY=IYF,IYL	MA004310
I=IY+IXIUY	MA004320
940 EMU(I)=EMT	MA004330
C	MA004340
C-----SET DO(IY) FOR IX=2 AND IX=NXM1.	MA004350
945 IF (KDOBT(IX).GT.1) GO TO 999	MA004360
IF (INC.EQ.1.AND.IX.EQ.NXM1) GO TO 994	MA004370
GO TO 996	MA004380
994 DO 995 IY=IYF,IYL	MA004390
995 DO(IY)=1.0	MA004400
GO TO 999	MA004410
996 IF (INC.EQ.-1.AND.IX.EQ.2) GO TO 997	MA004420
GO TO 999	MA004430
997 DO 998 IY=IYF,IYL	MA004440
998 DO(IY)=J.0	MA004450
999 CONTINUE	MA004460
C-----	MA004470
CHAPTER 10 10 10 10 10 ADJUST 10 10 10 10 10 10	MA004480
C-----	MA004490
C OVERALL CONTINUITY CORRECTION	MA004500
C ADJUST(1) ADJUSTS ALL THE U-VELOCITIES ON THE LINE IXU FOR	MA004510
C CONTINUITY ACROSS THE STRIP.	MA004520
C IF (IXU.EQ.NXM1.OR.IXU.EQ.1) GO TO 1001	MA004530
C CALL FLOWM(2)	MA004540
C IF (KTEST.GT.2) CALL TEST(40)	MA004550
C CALL ADJUST(1)	MA004560
C IF(KTEST.GT.1) CALL TEST(22)	MA004570
C-----	MA004580
C CELL-WISE CONTINUITY CORRECTION	MA004590
C 1001 CALL FLOWM(1)	MA004600
C CALL FLOWM(2)	MA004610
C IF (KTEST.GT.2) CALL TEST(40)	MA004620
C LADPHI=JPP	MA004630
C IF (RSOLVE(JPP).EQ.0) GO TO 1000	MA004640
C CALL CORR(JPP)	MA004650
C	MA004660
C ADJUST(2) ADJUSTS THE U AND V-VELOCITIES FOR EACH CELL ON	MA004670
C THE LINE IX FOR CONTINUITY IN THE CELL	MA004680
C CALL ADJUST(2)	MA004690

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                                IF (KTEST.GT.1) CALL TEST(23)
                                MA004690
                                IF (IXU.EQ.0.OR.IXU.EQ.1) GO TO 1000
                                MA004700
                                CALL ADJUST(3)
                                MA004710
                                IF (KTEST.GT.1) CALL TEST(24)
                                MA004720
C
                                MA004730
                                1000 CONTINUE
                                MA004740
C-----
                                MA004750
CHAPTER 11 11 11 11 11 PRINT 11 11 11 11 11 11 11
C-----
                                MA004760
C
                                MA004770
C
                                MA004780
C
                                MA004790
C
                                MA004800
C
                                MA004810
C
                                MA004820
C
                                MA004830
C
                                MA004840
C
                                MA004850
C
                                MA004860
C
                                MA004870
C
                                MA004880
C
                                MA004890
C-----
                                MA004900
CHAPTER 12 12 12 12 12 DECIDE 12 12 12 12 12 12 12
C-----
                                MA004910
C
                                MA004920
C
                                MA004930
C
                                MA004940
C
                                MA004950
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C
                                MA004990
C
                                MA005000
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                                MA005010
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                                MA005100
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                                MA005110
C
                                MA005120
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                                MA005130
C
                                MA005140
C
                                MA005150
C
                                MA005160
C
                                MA005170
C
                                MA005180
C
                                MA005190
C
                                MA005200

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1200 RMAX=A *1(RSMAX,RSSUM(J))	MA005210
C	MA005220
C.....DECISIONS CONCERNING SPECIAL PRINTOUT ARRANGEMENTS	MA005230
C	MA005240
IF (MOD (IS_EEP,1PRINT).EQ.0.AND.ISWEEP.NE.LSWEEP) CALL OUTPUT(2)	MA005250
C	MA005260
C.....DECIDE WHETHER TO CONTINUE SOLUTION	MA005270
C	MA005280
IF (RSMAX.GT.CCHECK.AND.ISWEEP.LT.LSWEEP) GO TO 50	MA005290
C	MA005300
C.....FINAL PRINTOUT	MA005310
CALL OUTPUT(2)	MA005320
STOP	MA005330
END	MA005340

SUBROUTINE OUTPUT(KGOTO)															00000010
C-----															00000020
CHAPTER	0	0	0	0	0	0	DECLARATIONS	0	0	0	0	0	0	0	00000030
C-----															00000040
COMMON/CO A/ (1400),V(475),H(500),FM(500),FUE(500),FS(500,15),															00000050
1 IP(20),TFM(500),P(414),RHO(500),EMU(500),															00000060
1 IXG(25),RXU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),															00000070
2 STORE(25),SXG(25),SXU(25),X(25),XU(25),															00000080
3 A(20),AE(20),AH(20),AREAE(20),AS(20),ASNIP(20),AW(20),B(20),															00000090
4 BSNIP(20),C(20),CSNIP(20),DIFE(20),DIFEE(20),DIFN(20),															00000100
5 DIFE(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),															00000110
6 FLOWL(20),FLOWEL(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),															00000120
7 PDYG(20),RDYV(20),RSYG(20),RSYV(20),RV(20),RVCR(20),RVSQ(20),															00000130
8 SP(20),SU(20),SYG(20),SYV(20),Y(20),YV(20),AEDOX(500),															00000140
9 ANDDY(500),AREAN(500),VOL(500),															00000150
X ARSL(25,25),PRIFF(25),PRL(25),PRT(25),RSLINE(25,25),															00000160
1 IEW(25),LAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),															00000170
2 KSRCE(25),KSNIP(25),TITL(25)															00000180
DIMENSION DIFNW(20),DIFFW(20),F(11009),FLOWNW(20),FLOWWW(20)															00000190
EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),															00000200
1 FLOWEL(1)),(DIFNW(1),DIFNE(1)),(DIFFW(1),DIFEE(1))															00000210
COMMON/COMB/															00000220
1 AK,ARRCON,BIG,CHECK,CHIX,DATA(6),UP,EL1,EL2,EMA,EMF,EMUREF,															00000230
2 IPST,ERAT,EWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,															00000240
3 FSTOIM,FJB,FJC,HFU,HV,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,															00000250
4 ISWEEP,IX,IXMON,IXPREF,IXP1,IXU,IXUP1,IXW,IXINY,IXINYU,															00000260
5 IXINY1,IX2NYH,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,															00000270
6 IYPREF,IYW,IYWM1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHQ,															00000280
7 JS1,JS2,JTEN,JU,JV,KASL,KINFRI,KLT,KRAD,KRIHOMU,KSWEET,KTEST,															00000290
8 LABPHI,LSWEEP,LSOLVE,NTDMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,															00000300
9 LXM2,U/Y,UXYP,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OXG,OXG,PCJAY,															00000310
X IREFXP,PCSS,RFLAXP,RF,RFSTM,RSCHEK,RSMAX,R11,R10,R21,R20,															00000320
1 STOICH,TR,TC,TINY,TMAX,TMIN,UB,UC,WMIX															00000330
LOGICAL CONVG															00000340
COMMON /INDEX/ IDCO,IDCO2,IDE,IDEH,IDEH2,IDEH20,IDO,IDOH,IDO2,IDN,															00000350
1 IDH,IDEH2,IDEH2,IDEH20,IEQUIL,IHCPS,IPR,JJ,KNTCS,NA,NLM,															00000360
2 NS,NSL1,NSF2,NSK,NSM,NS1,NS2,ID(4,15)															00000370
3/PARAMS/ CONVG,EMV,EPSS,GASCON,IDEBUG,ITMAX,PA,SM,TINYK,TK,TLN,TNY															00000380
5/SPECES/ASUB(20,3),CPSUM,HSUM,H0(14),SMW(14),S0(14),S1(14),															00000390
6 S2(14),Z(2,7,14)															00000400
7/CEQUIL/AC1,AC2,AC3,AC4,AH1,AH2,AH3,AH4,ASM1,ASM2,ASM3,ASM4,															00000410
8 AS1(4,7,2),HDTV,HMAX,HMIN,PEXP(7)															00000420
9/REALTS/RV(15),RX2(15),TACT(15),TACT2(15),TEN(15),TEN2(15)															00000430
C-----															00000440
CHAPTER	1	1	1	1	1	PRELIMINARIES	1	1	1	1	1	1	1	1	00000450
C-----															00000460
DATA RTIP/2/															00000470
DATA BLANK/4H /,THIRD/4H /															00000480
C-----															00000490
CHAPTER	2	2	2	2	2	HEADINGS	2	2	2	2	2	2	2	2	00000500
C-----															00000510
C-----															00000520


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      IF (RGOTO.HL.1) GO TO 3600
C-----
C----- PROBLEM INFORMATION
      R1Y=4.0*(FLOB+FLOC)/(LMUREF*R1I)
      CBRAT=1.01*STOICH/(OXC*(FLOC+TINY))
      WRITE (6,1007)
1007 FORMAT (11,1)
      WRITE (6,1013)
1013 FORMAT (11X,51(1H*)/11X,1H*,49X,1H*/11X,1H*,49X,1H*/11X,1H*,49X,
1 1H*/11X, 51H* PREDICTION OF HYDRODYNAMICS AND */OU000620
262H * */OU000630
362H * CHEMISTRY OF A TWO-CONCENTRIC-TUBE */OU000640
462H * */OU000650
562H * COMBUSTOR WITH ATTENTION */OU000660
662H * */OU000670
762H * TO POLLUTANT FORMATION */OU000680
8 11X,1H*,49X,1H*/11X,1H*,49X,1H*/11X,1H*,49X,1H*/11X,1H*,49X,1H*/
9 11X,1H*,49X,1H*/11X,1H*,49X,1H*) OU000690
      WRITE (6,1015)
1015 FORMAT(11X,1H*,10X, 40HTHE NASCO II COMPUTER PROGRAM */OU000720
162H * */OU000730
242H * PREPARED BY:19X,1H*/11X,1H*,49X,OU000740
3 1H*/11X,1H*, 6X,44HCONCENTRATION, HEAT AND MOMENTUM LTD. */OU000750
4 11X,1H*,49X,1H*/11X,1H*,23X,3HFOR,23X,1H*/11X,1H*,49X,1H*/ OU000760
562H * NATIONAL AERONAUTICS AND SPACE ADMINISTRATION */OU000770
662H * */OU000780
762H * NASA LEWIS RESEARCH CENTER */OU000790
8 11X,1H*,49X,1H*/11X,1H*,49X,1H*/11X,1H*,49X,1H*/11X,1H*,49X,1H*/
9 11X,1H*,15X,19HCONTRACT NASW-3077,15X,1H*/11X,1H*,49X,1H*) OU000800
      WRITE (6,1016) KASE OU000810
1016 FORMAT(11X,1H*,20X,10HAPRIL 1978,19X,1H*/ OU000820
1 11X,1H*,49X,1H*/11X,1H*,49X,1H*/11X,1H*,49X,1H*/11X,1H*,49X,1H*/
2 11X,1H*,49X,1H*/11X,1H*,49X,1H*/11X,1H*,49(1H-),1H*/ OU000830
3 11X,1H*,49X,1H*/11X,1H*,49X,1H*/11X,1H*,49X,1H*/11X,1H*,49X,1H*/
445H * RESULTS FOR TEST CASE,15,11X,1H*/11X, OU000840
5 1H*,49X,1H*/11X,1H*,10X,30H5.1. UNITS ARE USED THROUGHOUT,9X,1H*/OU000850
6 11X,1H*,49X,1H*/11X,1H*,49X,1H*/11X,1H*,49X,1H*/11X,1H*,49X,1H*/
7 11X,51(1H*)) OU000860
      WRITE (6,1020) OU000870
1020 FORMAT (11H,15HFLOW CONDITIONS/1X,15(1H=)) OU000880
      IF (KLT.EQ.1) WRITE (6,1021) OU000890
1021 FORMAT (11H,4X,14HLAMINAR, KLT=1) OU000900
      IF (KLT.EQ.2) WRITE (6,1022) OU000910
1022 FORMAT (11H,4X,16HTURBULENT, KLT=2) OU000920
      IF (INERT.EQ.1) WRITE (6,1023) OU000930
1023 FORMAT (11H,4X,21HNON-REACTING, INERT=1//) OU000940
      IF (INERT.EQ.2) WRITE (6,1024) OU000950
1024 FORMAT (11H,4X,20HCHEMICALLY REACTING, INERT=2//) OU000960
      WRITE (6,1019) OU000970
1019 FORMAT (11H,8HGEOMETRY/1X,8(1H=)) OU000980
      WRITE (6,210) PF,R1I,R1O,R2I,R2O,EL1,EL2 OU000990
210 FORMAT(/1X,10H RF,10H R1I,10H R1O, OU001000
      OU001010
      OU001020
      OU001030
      OU001040

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1100      R21,10H      R20/1X,1P5E10.2//1X,10H      EL1,      00001050
2100      EL2/1X,1P2E10.2)      00001060
      WRITE (6,1027) CMF,EMA,UB,UC,TB,TC,PRESS,REY,EQRAT,FLOWIN      00001070
1027 FORMAT (//1H0,16HINLET CONDITIONS/1X,16(1H=)//5X,      00001080
X 22HFLOW RATE OF FUEL, LMF,12X,1PE10.3//5X,      00001090
Y 21HFLOW RATE OF AIR, LMA,13X,1PE10.3//5X,      27HVELOCITY OF FLOW0001100
1 FUEL STREAM, MB,7X,1PE10.3//5X,26HVELOCITY OF AIR STREAM, UC,AX, 00001110
2 1PE10.3//5X,30HTEMPERATURE OF FUEL STREAM, TB,4X,1PE10.3//5X, 00001120
3 29HTEMPERATURE OF AIR STREAM, TC,5X,1PE10.3//5X,21HINLET PRESSURE0001130
4, PRESS,13X,1PE10.3//5X,15HREYNOLDS NUMBER,19X,1PE10.3//5X, 00001140
5 34HNOXIAL EQUIVALENCE RATIO, EQRAT ,1PE10.3//5X, 20HTOTAL MASS0001150
6 FLOW RATE, FLOWIN,6X,1PE10.3//)      00001160
      WRITE (6,1031)      00001170
1031 FORMAT(1H1,53HPOLYNOMIAL COEFFICIENTS FOR THERMODYNAMIC PROPERTIES0001180
1.761H 14 COEFFICIENTS ((Z(K,J,I),J=1,7),K=1,2) FOR EACH SPECIES I.0001190
2//)      00001200
      DO 1088 I=1,MSZ2      00001210
1088 WRITE (6,1082) ASUB(I,1),((Z(K,J,I),J=1,7),K=1,2)      00001220
1082 FORMAT (1H0,A4/(3X,1P6E11.3))      00001230
      IF (KUT(S.EJ,0) GO TO 1085      00001240
      WRITE (6,1085)      00001250
1085 FORMAT (1H1,16HREACTION MECHANISM/1X,16(1H=))      00001260
      DO 1061 J=1,JJ      00001270
      DO 1060 KK=1,6      00001280
      LL=KK      00001290
      IF (KK.GT.5) LL=KK-1      00001300
      DATA (KK)=BLANK      00001310
      IF (KK.LQ.3) GO TO 1060      00001320
      IF (KK.LQ.6) GO TO 1060      00001330
      IDLLJ=IS(I,LL,J)      00001340
      IF (IDLLJ.EQ.0) GO TO 1060      00001350
      DATA (KK)=ASUB(IDLLJ,1)      00001360
1060 CONTINUE      00001370
      IF (IS(2,J).EQ.0) GO TO 1062      00001380
      IF (IS(4,J).EQ.0) GO TO 1062      00001390
      GO TO 1063      00001400
1062 DATA(3)=THIRD      00001410
      DATA(6)=THIRD      00001420
      WRITE (6,1064) J,(DATA(K),K=1,6)      00001430
1064 FORMAT (13,2H, ,A4,2H+ ,A4,2H+ ,A4,2H= ,A4,2H+ ,A4,2H+ ,A4, 00001440
1 1P3E11.3)      00001450
      GO TO 1061      00001460
1063 WRITE (6,1065) J,(DATA(K),K=1,6)      00001470
1065 FORMAT (13,2H, ,A4,2H+ ,A4,2X,A4,2H= ,A4,2H+ ,A4,2X,A4,1P3E11.3) 00001480
1061 CONTINUE      00001490
      WRITE (6,1084) (J,BX(J),TEN(J),TACT(J),BX2(J),TEN2(J),TACT2(J), 00001500
1 J=1,JJ)00001510
1084 FORMAT (1H0,2X,24HRATE CONSTANT PARAMETERS/5X,37HRATE CONSTANT = 00001520
1 A*T+B+C*P(-TACT/T),10X,15H(T=TEMPERATURE)///17X,12HFORWARD RATE,00001530
2 21X,13HBACKWARD RATE//9X,1HA,10X,1HR,8X,4HTACT,9X,1HA,10X,1HR,8X,00001540
3 4HTACT/((3,1H, ,1P6E11.3))      00001550
1085 WRITE (6,240) NX,NY,NXMAX,NYMAX      00001560

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	WRITE (6,251) NTDMA,LSWEEP,RSCHEK,CHECK	OU001570
250	FORMAT(/1X,10H NX,10H NY,10H NXMAX,10H NYMAX,10H)	OU001580
	1/1X,4(10)	OU001590
251	FORMAT(/1X,10H NTDMA,10H LSWEEP	OU001600
	1,10H RSCHEK,10H CHECK/1X,2I10,1P2E10.2)	OU001610
	RETURN	OU001620
C	-----	OU001630
CHAPTER 3	3 3 3 3 3 FIELD VALUES 3 3 3 3 3 3 3 3 3	OU001640
C	-----	OU001650
	3000 IF (KSOLO.NE.2) GO TO 4000	OU001660
	DO 31 JPHI=1,JLAST	OU001670
	IF (JPHI.EQ.JPP) GO TO 31	OU001680
	IF (KSOLVE(JPHI).EQ.0) GO TO 31	OU001690
	CALL PRINT(JPHI)	OU001700
31	CONTINUE	OU001710
	KIRIP=0	OU001720
	RETURN	OU001730
C	-----	OU001740
CHAPTER 4	4 4 4 4 PRINT OUT OF RESIDUAL SOURCES AND MONITORING VALUES	OU001750
C	-----	OU001760
	4000 IF (KSOLO.NE.3) RETURN	OU001770
	IF (MOD(JSWEEP,IPLRS).NE.0) GO TO 4140	OU001780
	KIRIP=0	OU001790
	WRITE (6,4100) ISWEEP,ISWEEP,(TITLE(K),K=1,NSOLVE),TITLE(JPP)	OU001800
	DO 416 IX=2,NXM1	OU001810
416	WRITE (6,4102) IX,KOUNT(IX),(RSLINE(IX,J),J=1,NSOLVE),RSLINE(IX,JPP)	OU001820
	WRITE (6,4104) IXFROM,IYMON,(TITLE(K),K=1,NSOLVE),TITLE(JP)	OU001830
	DO 417 J=1,NSOLVE	OU001840
	I=IMON(J)+IZERO(J)	OU001850
417	STORE(J)=F(I)	OU001860
	I=IMON(JP)	OU001870
	WRITE (6,4112) ISWEEP,(STORE(J),J=1,NSOLVE),P(I)	OU001880
4140	IF (KIRIP.EQ.0) WRITE(6,4113) (TITLE(K),K=1,NSOLVE),TITLE(JPP)	OU001890
	KIRIP=1	OU001900
	WRITE (6,4112) ISWEEP,(RSSUM(J),J=1,NSOLVE),RSSUM(JPP)	OU001910
4100	FORMAT(/1X,10HJSWEEP NO. ,13,2X,80(1H=),4X,10HJSWEEP NO. ,13//1X,	OU001920
	163H)ALGEBRAIC SUM OF RESIDUAL SOURCES AT EACH LINE--RSLINE(IX,JPHI)	OU001930
	2/1X,13HIX NO. TRAVS,2X,10(3X,A4,3X))	OU001940
4102	FORMAT(1X,12,6X,12,3X,1P10E10.2)	OU001950
4104	FORMAT(/1X,31HVALUES AT MONITORING LOCATION (,12,1H,,12,1H)/	OU001960
	16X,6HJSWEEP,3X,10(3X,A4,3X))	OU001970
4112	FORMAT(1X,13,6X,1P10E10.2)	OU001980
4113	FORMAT(/1X,38H)SUM OF ABS. VALUES OF RSLINE(IX,JPHI)--/	OU001990
	1 1X,6HJSWEEP,3X,10(3X,A4,3X))	OU002000
	RETURN	OU002010
	END	OU002020

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SUBROUTINE PHIL(LEPHI)										PR000010	
C-----										PR000020	
CHAPTER	0	1	0	0	0	DECLARATIONS	0	0	0	0	PR000030
C											PR000040
COMMON/CO. A/ (1480),V(475),H(500),FM(500),FUE(500),FS(500,15),										PR000050	
1 PP(20),TMM(500),P(414),RHO(500),EMU(500),										PR000060	
1 IXG(25),IXU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),										PR000070	
2 STORL(5),SXG(25),SXU(25),X(25),XU(25),										PR000080	
3 A(20),F(20),AH(20),AREAC(20),AS(20),ASNIP(20),AW(20),B(20),										PR000090	
4 LSHIP(20),C(20),CSNIP(20),DIFE(20),DIFEE(20),DIFN(20),										PR000100	
5 DIFNE(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),										PR000110	
6 FLOWG(20),FLOWEE(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),										PR000120	
7 RPY(20),RHYV(20),RSYG(20),RSYV(20),RV(20),RVCR(20),RVSQ(20),										PR000130	
8 SP(20),SU(20),SYG(20),SYV(20),Y(20),YV(20),AEDUX(500),										PR000140	
9 ANDDY(500),AREAN(500),VOL(500),										PR000150	
X ARSL(25,25),PREF(25),PRL(25),PRT(25),RSLINE(25,25),										PR000160	
1 IEW(25),ILAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),										PR000170	
2 KSHFF(25),RSSUM(25),TITLE(25)										PR000180	
DIMENSION DIFNW(20),DIFWW(20),F(1189),FLOWNW(20),FLOWWW(20)										PR000190	
EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),										PR000200	
1 FLOWEE(1)),(DIFNW(1),DIFNE(1)),(DIFWW(1),DIFEE(1))										PR000210	
COMMON/CONV/										PR000220	
1 AK,ARRCON,BIG,CHECK,CMIX,DATA(6),UP,EL1,EL2,EMA,EMF,EMUREF,										PR000230	
2 EPST,EPRAT,EWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,										PR000240	
3 I STOIM,FUB,FUC,HFU,Hw,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,										PR000250	
4 ISWEEP,IX,IXMON,IXPREF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,										PR000260	
5 IX1NY1,IX2NYU,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,										PR000270	
6 IYPHCF,IYW,IYWM1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,										PR000280	
7 JS1,JS2,JTEM,JU,JV,KASE,KINPRI,KLT,KRAD,KRHOMU,KSWEET,KTFST,										PR000290	
8 LABFHI,LSWEEP,NSOLVE,NTDMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,										PR000300	
9 NXM2,NXY,NXYX,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OXB,OXD,PJAY,										PR000310	
X I RELXP,PRESS,RELAXP,RF,RFSTM,RSCHK,RSMAX,R1I,R1O,R2I,R2O,										PR000320	
1 STOICH,TC,TC,TINY,TMAX,TMIN,UB,UC,WMIX										PR000330	
LOGICAL CONVG										PR000340	
COMMON /INDEX/ IDCO,IDCG2,IDF,IDH,IDH2,IDH20,IDO,IDOH,IDO2,IDN,										PR000350	
1 IDH,IDO2,IDH2,IDH20,IEQUIL,IHCPS,IPR,JJ,KNTCS,NA,NLM,										PR000360	
2 HS,USE1,USE2,HSK,NSM,NS1,NS2,ID(4,15)										PR000370	
3/PARAMS/ CONVG,ENV,LPSS,GASCON,IDEBUG,ITMAX,PA,SM,TINYK,TK,TLN,TNY										PR000380	
5/SPECIES/ASUB(20,3),CPSUM,HSUM,H0(14),SMW(14),S0(14),S1(14),										PR000390	
6 S2(14),Z(2,7,14)										PR000400	
7/CEQUIL/AC1,AC2,AC3,AC4,AH1,AH2,AH3,AH4,ASM1,ASM2,ASM3,ASM4,										PR000410	
8 ASI(4,7,2),HIDIV,HMAX,HMIIH,PEXP(7)										PR000420	
9/REACTS/BX(15),BX2(15),TACT(15),TACT2(15),TEN(15),TEN2(15)										PR000430	
C-----										PR000440	
CHAPTER	1	1	1	1	1	PRELIMINARIES	1	1	1	1	PR000450
C											PR000460
JPHI=LEPHI										PR000470	
IF (JPHI.EQ.JP) GO TO 12										PR000480	
C-----										PR000490	
FOR ALL PHI'S EXCEPT P										PR000500	
KOLUN1=1										PR000510	
KOLUN2=HUMCOL										PR000520	

10	LIMIT1=KOLUM1	PR000530
	LIMIT2=KOLUM2	PR000540
	LTOP=ILOC(JPHI)	PR000550
	LBOT=1	PR000560
	IF (JPHI-NI.00) GO TO 11	PR000570
C	-----	PR000580
	IF (LIMIT1.GT.NXM1) LIMIT1=NXM1	PR000590
	IF (LIMIT2.GT.NXM1) LIMIT2=NXM1	PR000600
	GO TO 20	PR000610
C	-----	PR000620
	OTHER PHIS	PR000630
11	IF (LIMIT1.GT.NX) LIMIT1=NX	PR000640
	IF (LIMIT2.GT.NX) LIMIT2=NX	PR000650
	GO TO 20	PR000660
C	-----	PR000670
	FOR P	PR000680
12	KOLUM1=2	PR000690
	KOLUM2=IUMCOL+1	PR000700
13	LIMIT1=KOLUM1	PR000710
	LIMIT2=KOLUM2	PR000720
	IF (LIMIT1.GT.NXM1) LIMIT1=NXM1	PR000730
	IF (LIMIT2.GT.NXM1) LIMIT2=NXM1	PR000740
	LTOP=IY+1	PR000750
	LBOT=2	PR000760
C	-----	PR000770
	CHAPTER 2 2 2 2 2 PRINT TITLE OF VARIABLES 2 2 2 2 2 2	PR000780
C	-----	PR000790
20	WRITE(6,200) TITLE(JPHI),TITLE(JPHI)	PR000800
200	FORMAT(71X,15HFIELD VALUES OF,1X,A4,2X,22(1H-),A4,22(1H-))	PR000810
C	-----	PR000820
	CHAPTER 3 3 3 3 3 PRINT FIELD VALUES 3 3 3 3 3 33	PR000830
C	-----	PR000840
	DO 39 IY=LBOT,LTOP	PR000850
	IY=LTOP-IY+LBOT	PR000860
	DO 30 IX=LIMIT1,LIMIT2	PR000870
	IF (JPHI-JI) 301,31,301	PR000880
301	IF (JPHI-JV) 302,32,302	PR000890
302	IF (JPHI-JJ) 303,33,303	PR000900
303	CONTINUE	PR000910
31	I=IY+(IX-1)*NY	PR000920
	GO TO 3000	PR000930
32	I=IY+(IX-1)*NYM1	PR000940
	GO TO 3000	PR000950
33	I=IY-1+(IX-2)*NYM2	PR000960
3000	I=I+IZERO(JPHI)	PR000970
30	STORE(IX)=F(I)	PR000980
	IF (JPHI-JV) 310,311,310	PR000990
310	WRITE(6,3100) IY,Y(IY),(STORE(IX),IX=LIMIT1,LIMIT2)	PR001000
	GO TO 30	PR001010
311	WRITE(6,3101) IY,YV(IY),(STORE(IX),IX=LIMIT1,LIMIT2)	PR001020
39	CONTINUE	PR001030
	IF (JPHI-JI) 320,321,320	PR001040
320	WRITE(6,3102) IY,X(IX),IX=LIMIT1,LIMIT2	
	GO TO 300	

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321	WRITE(6,3103)(IX,XU(IX),IX=LIMIT1,LIMIT2)	PR001050
360	IF (JPH1.EQ.00) GO TO 350	PR001060
	IF (JPH1.EQ.00) GO TO 350	PR001070
C-----	FOR ALL PHIS OTHER THAN U AND P	PR001080
	IF (LIMIT2.LQ.NX) RETURN	PR001090
	KOLU1=FOI UM1+NUMCOL	PR001100
	KOLU2=FOI UM2+NUMCOL	PR001110
	GO TO 10	PR001120
C-----	FOR U AND P	PR001130
350	IF (LIMIT2.LQ.NXM1) RETURN	PR001140
	KOLU1=FOI UM1+NUMCOL	PR001150
	KOLU2=FOI UM2+NUMCOL	PR001160
	IF (JPH1.EQ.00) GO TO 10	PR001170
	GO TO 13	PR001180
3100	FORMAT(1X,1X,5HY(,12,2H)=,1PE9.3,2X,10(1PE9.2,1X))	PR001190
3101	FORMAT(1X,3HYV(,12,2H)=,1PE9.3,2X,10(1PE9.2,1X))	PR001200
3102	FORMAT(75X,5HX(1X), 9X,10(12,1H=,F6.3,1X)/)	PR001210
3103	FORMAT(75X,6HXU(1X), 8X,10(12,1H=,F6.3,1X)/)	PR001220
	END	PR001230

SUBROUTINE BOUND	80000010
C=HNO/2.0/AZ H(400),V(475),H(500),FM(500),FUE(500),FS(500,15),	80000020
1 I(20),TEM(500),P(414),RHO(500),EMU(500),	80000030
1 IXG(25),IXY(25),KONIF(25),RDYG(25),RDYU(25),RSXG(25),RSXU(25),	80000040
2 STORE(25),SXG(25),SXU(25),X(25),XU(25),	80000050
3 A(20),L(20),AH(20),AREAE(20),AS(20),ASNIP(20),AW(20),B(20),	80000060
4 ISHIP(20),C(20),CSNIP(20),DIFE(20),DTFEE(20),DIFM(20),	80000070
5 IIFM(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),	80000080
6 FLOW(20),FLOWL(20),FLOWN(20),FLOWNF(20),FLOWN(20),R(20),	80000090
7 RDY(20),RDYV(20),RSYG(20),RSYV(20),RV(20),RVCH(20),RVSQ(20),	80000100
8 SP(20),S(20),SYG(20),SYV(20),Y(20),YV(20),AEDDX(500),	80000110
9 ADUHY(500),ARFAH(500),VOL(500),	80000120
X ARSL(25,25),PRIF(25),PRL(25),PRT(25),RSLINE(25,25),	80000130
1 LEW(25),LAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),	80000140
2 KSRLE(25),RSSUM(25),TITLE(25)	80000150
DIMENSION DIFMW(20),DIFWW(20),F(1189),FLOWNW(20),FLOWWW(20)	80000160
EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),	80000170
1 FLOWF(1)),(DTINW(1),DIFNE(1)),(DIFWW(1),DIFEE(1))	80000180
COMMON/COMMON/	80000190
1 AK,ARRON,BIG,CHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,	80000200
2 LPST,ERRAT,EWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,	80000210
3 ISTEIN,FUB,IUC,HFU,HW,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,	80000220
4 ISHEL,P,IX,IXMON,IXPRLF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,	80000230
5 IX1NY1,IX2NYU,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,	80000240
6 IYPRF,IYW,IYW1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,	80000250
7 JS1,JS2,JTEM,JU,JV,KASE,KINPRI,KLT,KRAD,KRHOMU,KSWEPT,KTEST,	80000260
8 LABPHI,LSWEEP,MSOLVE,NTDMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NYM1,	80000270
9 LXM2,HYB,HXYP,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OXB,OXC,PJAY,	80000280
X IREL,YP,PRESS,RELAXP,RF,RFSTM,RSCHK,RSMAX,R11,R10,R21,R20,	80000290
1 STOICH,TB,TC,TINY,TMAX,TMIN,UB,UC,WMIX	80000300
C-----	80000310
C UPDATE VALUES ON BOUNDARIES FOR PRINTOUT PURPOSES	80000320
C-----	80000330
JPHIELAPHI	80000340
IF (JPHI.EQ.JU) GO TO 10	80000350
IF (JPHI.EQ.JH) GO TO 40	80000360
IF (JPHI.EQ.JEM) GO TO 50	80000370
IF (JPHI.EQ.JPUP) GO TO 60	80000380
IF (JPHI.EQ.JTEM) GO TO 110	80000390
IF (JPHI.EQ.JP) GO TO 120	80000400
IF (JPHI.EQ.JRHO) GO TO 130	80000410
IF (JPHI.EQ.JEM1) GO TO 140	80000420
RETURN	80000430
C-----	80000440
C U AT AXIS OF PIPE	80000450
10 I=1+IX1NYU	80000460
U(1)=U(1)+1	80000470
C-----	80000480
C UPDATE U AT PIPE EXIT	80000490
IF (IXU.NE.2) RETURN	80000500
IF (INC.EQ.1) RETURN	80000510
DO 12 IY=IYWP1,NYU1	80000520

I=IY+IX*NY	B0000530
IV=I-IV	B0000540
12 U(IW)=U(I)	B0000550
RETURN	B0000560
C	B0000570
C-----UPDATE H ON BOUNDARIES.	B0000580
C-----AT PIPE AXIS.	B0000590
40 I=1+IX*NY	B0000600
H(I)=H(I+1)	B0000610
I=1+IX*NY	B0000620
H(I)=H(I+1)	B0000630
C-----UPDATE H AT EXIT	B0000640
IF (IX.NE.2) RETURN	B0000650
IF (INC.(0.1) RETURN	B0000660
DO 42 IY=IY+NY	B0000670
I=IY+IX*NY	B0000680
IV=I-IV	B0000690
42 H(IW)=H(I)	B0000700
RETURN	B0000710
C	B0000720
C-----UPDATE MIXTURE FRACTION ON BOUNDARIES.	B0000730
C-----AT PIPE WALL.	B0000740
50 I=NY+IX*NY	B0000750
FM(I)=FM(I-1)	B0000760
C-----AT PIPE AXIS.	B0000770
I=1+IX*NY	B0000780
FM(I)=FM(I+1)	B0000790
C-----SET MIXTURE FRACTION AT NODES IN THE INNER WALL TO ZERO.	B0000800
IF (IX.GT.IXW) GO TO 51	B0000810
I=IY+IX*NY	B0000820
FM(I)=0.0	B0000830
C-----AT PIPE EXIT.	B0000840
51 IF (IX.LE.2) GO TO 53	B0000850
IF (INC.(0.1) GO TO 53	B0000860
DO 52 IY=IY+NY	B0000870
I=IY+IX*NY	B0000880
IV=I-IV	B0000890
52 FM(IW)=FM(I)	B0000900
53 IF (IX.NE.IXW) RETURN	B0000910
DO 54 IY=IY+NY	B0000920
I=IY+IX*NY	B0000930
IV=I-IV	B0000940
54 FM(IW)=FM(I)	B0000950
RETURN	B0000960
C	B0000970
C-----UPDATE FULL MASS FRACTION ON BOUNDARIES.	B0000980
C-----AT PIPE WALL.	B0000990
60 I=NY+IX*NY	B0001000
FUE(I)=FUE(I-1)	B0001010
C-----AT PIPE AXIS.	B0001020
I=1+IX*NY	B0001030
FUE(I)=FUE(I+1)	B0001040

C-----SET FUEL MASS FRACTION AT NODES IN THE INNER WALL TO ZERO.	B0001050
IF (IX.GT.IXW) GO TO 610	B0001060
I=IY+IX*NY	B0001070
FUE(I)=0.0	B0001080
C-----AT PIPE EXIT.	B0001090
610 IF (IX.LE.2) GO TO 630	B0001100
IF (INC.EQ.1) GO TO 630	B0001110
DO 620 IY=IYWP1,NY	B0001120
I=IY+IX*NY	B0001130
Iw=I-IY	B0001140
620 FUE(Iw)=FUE(I)	B0001150
630 IF (IX.NE.IXW1) GO TO 650	B0001160
DO 640 IY=1,NY	B0001170
I=IY+IX*NY	B0001180
Ie=1+IY	B0001190
640 FUE(Ie)=FUE(I)	B0001200
C	B0001210
C-----UPDATE SPECIES MASS FRACTIONS ON BOUNDARIES.	B0001220
C	B0001230
650 II=1+IX*NY	B0001240
INY=NY+IX*NY	B0001250
DO 61 J=JS1,JS2	B0001260
C-----AT PIPE WALL.	B0001270
IF=IIY+IZERO(J)	B0001280
F(IF)=F(IF-1)	B0001290
C-----AT PIPE AXIS.	B0001300
II=II+IZERO(J)	B0001310
61 F(IF)=F(IF+1)	B0001320
C-----SET SPECIES MASS FRACTIONS AT NODES IN THE INNER WALL TO ZERO.	B0001330
IF (IX.GT.IXW) GO TO 66	B0001340
I=IY+IX*NY	B0001350
DO 62 J=JS1,JS2	B0001360
IF=I+IZERO(J)	B0001370
62 F(IF)=0.0	B0001380
C-----AT PIPE EXIT.	B0001390
66 IF (IX.NE.2) GO TO 64	B0001400
IF (INC.EQ.1) GO TO 64	B0001410
DO 63 IY=IYWP1,NY	B0001420
I=IY+IX*NY	B0001430
DO 63 J=JS1,JS2	B0001440
IF=I+IZERO(J)	B0001450
IFW=IF-IY	B0001460
63 F(IFW)=F(IF)	B0001470
64 IF (IY.NE.IXW1) RETURN	B0001480
C-----AT PIPE WALL.	B0001490
DO 65 IY=1,NY	B0001500
I=IY+IX*NY	B0001510
DO 65 J=JS1,JS2	B0001520
II=I+IZERO(J)	B0001530
IFE=IF+IY	B0001540
65 F(IFE)=F(IF)	B0001550
RETURN	B0001560

C	80001570
C-----UPDATE TEMPERATURE ON BOUNDARIES.	800015A0
C-----AT PIPE AXIS.	80001590
110 I=1+IX1*Y	80001600
TEM(I)=TEM(I+1)	80001610
I=1+IXM1*Y	80001620
TEM(I)=TEM(I+1)	80001630
C-----AT PIPE EXIT.	80001640
IF (IX.NE.2) RETURN	80001650
IF (INC.LO.1) RETURN	80001660
DO 112 JY=IYW,NY	80001670
I=IY+IX1*NY	800016A0
IW=I-NY	80001690
112 TEM(IW)=TEM(I)	80001700
RETURN	80001710
C	80001720
C-----SET PRESSURE AT NODES IN THE INNER WALL TO ZERO.	80001730
C	80001740
120 IF (IX.GT.IXW) RETURN	80001750
I=IYW*1+IX2*NY2	80001760
P(I)=0.0	80001770
RETURN	800017A0
C	80001790
C-----UPDATE DENSITY ON BOUNDARIES.	80001800
C-----AT PIPE WALL.	80001810
130 I=NY+IX1*NY	80001820
RHO(I)=RHO(I-1)	80001830
C-----AT PIPE AXIS.	80001840
I=1+IX1*NY	80001850
RHO(I)=RHO(I+1)	80001860
C-----AT PIPE EXIT.	80001870
IF (IX.NE.2) RETURN	800018A0
IF (INC.LO.1) RETURN	80001890
DO 132 IY=IYWP1,NY	80001900
I=IY+IX1*NY	80001910
IW=I-NY	80001920
132 RHO(IW)=RHO(I)	80001930
RETURN	80001940
C	80001950
C-----UPDATE VISCOSITY ON BOUNDARIES.	80001960
C	80001970
C-----AT PIPE WALL.	800019A0
140 I=NY+IX1*NY	80001990
EMU(I)=EMU(I-1)	80002000
C-----AT PIPE AXIS.	80002010
I=1+IX1*NY	80002020
EMU(I)=EMU(I+1)	80002030
C-----AT PIPE EXIT.	80002040
IF (IX.NE.2) GO TO 141	80002050
IF (INC.LO.1) GO TO 141	80002060
DO 143 IY=IYWP1,NY	80002070
I=IY+IX1*NY	80002080

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      IX=I- IY
143  EQU(IN)=EQU(I)
141  IF (IX.LE.NAM1) RETURN
      UC 142 IY=1+IY
      I=IY+IX+IY
      IF=1+IY
142  EQU(IE)=EQU(I)
      RETURN
      END

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B0002090
B0002100
B0002110
B0002120
B0002130
B0002140
B0002150
B0002160
B0002170

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SUBROUTINE SOURCE(LPHI)																S0000010
C-----																S0000020
CHAPTER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S0000030
C-----																S0000040
C-----																S0000050
COMMON/COMA/ U(480),V(475),H(500),FM(500),FUE(500),FS(500,15),																S0000060
1 IP(20),TFM(500),P(414),RHO(500),EMU(500),																S0000070
1 DXG(25),DXU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),																S0000080
2 STORC(25),SXG(25),SXU(25),X(25),XU(25),																S0000090
3 A(20),AL(20),AH(20),AREAE(20),AS(20),ASNIP(20),AW(20),B(20),																S0000100
4 ESHIP(20),C(20),CSNIP(20),DIFE(20),DIFEE(20),DIFN(20),																S0000110
5 DIFIF(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),																S0000120
6 FLOWE(20),FLOWEL(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),																S0000130
7 RDYG(20),RDYV(20),RSYG(20),RSYV(20),RV(20),RVCH(20),RVSQ(20),																S0000140
8 SP(20),SH(20),SYG(20),SYV(20),Y(20),YV(20),AEDDX(500),																S0000150
9 ADDDY(500),AREAN(500),VOL(500),																S0000160
X ARSL(25,25),PRCF(25),FRL(25),PRT(25),RSLINE(25,25),																S0000170
1 IEW(25),ILAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),																S0000180
2 RSREF(25),RSSUM(25),TITLE(25)																S0000190
DIMENSION DIFFW(20),DIFWW(20),F(11889),FLOWNW(20),FLOWWW(20)																S0000200
EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),																S0000210
1 FLOWEE(1)),(DIFFW(1),DIFNE(1)),(DIFWW(1),DIFEE(1))																S0000220
COMMON/COMP/																S0000230
1 AK,ARRCON,BIG,CHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,																S0000240
2 EPSI,ERRAT,EWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,																S0000250
3 FSTOIM,FUE,FUC,HFU,HV,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,																S0000260
4 ISWLEP,IX,IXMON,IXPREF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,																S0000270
5 IX1NY1,IX2NY1,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,																S0000280
6 IYPREF,IYW,IYWM1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,																S0000290
7 JS1,JS2,JTEM,JH,JV,KASE,KINPRI,KLT,KRAD,KRIOMU,KSWEET,KTEST,																S0000300
8 LABPHI,LSWEEP,NSOLVE,NTDMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,																S0000310
9 NXM2,NXY,NXYP,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OXB,OXC,PJAY,																S0000320
X FREXP,PRESS,REFLXP,RF,RFSTM,RSCHK,RSMAX,R11,R10,R21,R20,																S0000330
1 STOICH,T3,TC,TINY,TMAX,TMIN,UB,UC,WMIX																S0000340
LOGICAL CONVG																S0000350
COMMON/INDEX/ IDCO,IDC02,IDF,IDH,IDH2,IDH20,IDO,IDOH,IDO2,IDN,																S0000360
1 IDN0,IDN02,IDN2,IDN20,IEQUIL,IHCP,IPR,JJ,KNTCS,NA,NLM,																S0000370
2 IS,ISE1,ISE2,ISK,NSM,NS1,NS2,ID(4,15)																S0000380
3/PARAMS/ CONVG,CMV,EPSS,GASCON,IDEBUG,ITMAX,PA,SM,TINYK,TK,TLN,TNY																S0000390
5/SPFLES/ASUB(20,3),CPSUM,HSUM,H0(14),SMW(14),SQ(14),S1(14),																S0000400
6 S2(14),Z(2,7,14)																S0000410
7/CEQNL/AC1,AC2,AC3,AC4,AH1,AH2,AH3,AH4,ASM1,ASM2,ASM3,ASM4,																S0000420
8 AS1(4,7,2),HDIV,HMAX,HMIN,PEXP(7)																S0000430
9/REACTS/RX(15),RX2(15),TACT(15),TACT2(15),TEN(15),TEN2(15)																S0000440
COMMON/IT/ ALNR11,ALNR10,ALNR21,ALNR20,COND,EL3,																S0000450
1 LMR10,LMR21,LMR20,EMISX1,EMISX0,REMI,RHOINF,																S0000460
1 SIGMA,TV1,STXG,ST11,ST10,ST21,ST20,TINF,VINF,WAREA																S0000470
C-----																S0000480
CHAPTER	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	S0000490
C-----																S0000500
DATA SHALE/0.04/																S0000510
JPHI=LPHI																S0000520

IF (JPHI.L.E.JU) GO TO 10	S0000530
IF (JPHI.L.E.JV) GO TO 20	S0000540
IF (JPHI.L.E.JH) GO TO 40	S0000550
IF (JPHI.L.E.JM) GO TO 50	S0000560
IF (JPHI.L.E.JUH) GO TO 60	S0000570
IF (JPHI.L.E.JPD) GO TO 90	S0000580
RETURN	S0000590
C-----	
CHAPTER 2 2 2 2 2 2 SOURCE TERMS FOR U 2 2 2 2 2 2 2 2	S0000600
C-----	S0000610
10 ICONST=IX*NTU-1	S0000620
IF (XNRH.MU.F.U.P) GO TO 12	S0000630
RDXUIX=RDUX(I XU)	S0000640
RDXUI1=RDUX(I XUP1)	S0000650
RSXUIX=RSXU(I XU)	S0000660
QDUX=C.25*RDXG(I XUP1)	S0000670
	S0000680
C	S0000690
I=IYFM1+IXIHYU	S0000700
IE=I+HY	S0000710
IN=I+1	S0000720
IIE=IN+Y	S0000730
IXUIY=(IXU-1)*IYFM1	S0000740
IV=IYFM1+IXUINY	S0000750
IFV=IV+HY-1	S0000760
EDVDM=(F(U(I)+EMU(IE)+EMU(IN)+EMU(IIE))*(V(IEV)-V(IV))*RV(IYFM1)	S0000770
DO 11 IY=IYF+1YL	S0000780
I=IY+IXIHYU	S0000790
IE=I+HY	S0000800
IN=I+1	S0000810
IIE=IN+Y	S0000820
IV=IY+IXUINY	S0000830
IFV=IV+HY-1	S0000840
IF=IY+ICD1ST	S0000850
IUP=IP+Y-12	S0000860
DUDX=(U(I)-U(IFW))*RDXUIX	S0000870
DUDX1=(U(IL)-U(I))*RDXUI1	S0000880
STERM=C.M1(IL)*DUDXE-EMU(IW)*DUDXW)*RSXUIX	S0000890
EDVXS=EDVDM	S0000900
EDVDM=(F(U(I)+EMU(IE)+EMU(IN)+EMU(IIE))*(V(IEV)-V(IV))*RV(IY)	S0000910
STERM=STERM+(EDVDM-EDVXS)*QRDXG/AREAF(IY)	S0000920
SU(IY)=AREAF(IY)*(P(IP)-P(ICP))+0.5*STERM*(VOL(I)+VOL(IE))	S0000930
SI(IY)=U(I)	S0000940
	S0000950
C----- THERMAL UNDER-RELAXATION -----	S0000960
AFAC=1.	S0000970
ASU=AFAC*ABS(SU(IY))	S0000980
AFACT=ASU/(ABS(U(I))+TINY)	S0000990
AFAT=1.E-5*ASU	S0001000
AFACT=MAX(1,AFACT,AFAT)	S0001010
SU(IY)=SU(IY)+AFACT*U(I)	S0001020
SP(IY)=SP(IY)-AFACT	S0001030
11 CONTINUE	S0001040

GO TO 14	S0001050
12 DO 13 IY=IYF,IYL	S0001060
IP=IY+I(0:ST	S0001070
ILP=IP+IY.2	S0001080
SO(IY)=ARFAL(IY)*(P(IP)-P(ILP))	S0001090
13 SP(IY)=0.0	S0001100
C	S0001110
14 IF(IYU.LO.IXW.AND.INC.EQ.-1) GO TO 1000	S0001120
GO TO 1002	S0001130
1000 DO 1001 IY=2,IYW	S0001140
I=IY+IXIHYU	S0001150
SO(IY)=PII*U(I)	S0001160
1001 SP(IY)=-BIG	S0001170
C-----EXTRA SOURCES DUE TO INNER TUBE:	S0001180
1002 IF (IXU.GT.IXW) RETURN	S0001190
IF (INC.HI.1) GO TO 15	S0001200
IP=IY+MI	S0001210
IS=IYW	S0001220
GO TO 16	S0001230
15 I2=IY+PI	S0001240
IS=IY+PI	S0001250
16 I=I2+IXIHYU	S0001260
RUREF=RHO(1)*ARS(U(I))	S0001270
RE=0.5*(UREF*DYG(I3)/EMUREF	S0001280
IF (KLT.LO.1) GO TO 19	S0001290
IF (RE.LT.162.25) GO TO 19	S0001300
ER=RE+EWALL	S0001310
ARGMIN=11.5*EWALL	S0001320
DO 17 HIT=1,11	S0001330
SHALF1=SHALF	S0001340
ARG=ER*SHALF	S0001350
IF (ARG.LT.ARGMIN) GO TO 19	S0001360
SHALF=AR/ALOG(ARG)	S0001370
IF (ABS(SHALF-SHALF1).LT.0.0001) GO TO 18	S0001380
17 CONTINUE	S0001390
18 S=SHALF**2	S0001400
SP(I2)=SP(I2)-S*R(I2)*RUREF*SXU(IXU)	S0001410
RETURN	S0001420
19 SP(I2)=SP(I2)-EMUREF*SXU(IXU)*R(I2)/(DYG(I3)*0.5)	S0001430
RETURN	S0001440
C-----	S0001450
CHAPTER 3 3 3 3 3 3 SOURCE TERMS FOR V 3 3 3 3 3 3 3 3 3 3	S0001460
C-----	S0001470
20 ICONST=IXPHY2-1	S0001480
IF (IX.EQ.2.AND.INC.EQ.-1) GO TO 25	S0001490
IF (KRHOHI.EQ.0) GO TO 22	S0001500
QPSXG=0.25*RSXG(IX)	S0001510
IL=IYF+IXIHY	S0001520
IV=IYFI+IXIHY1	S0001530
ELVDYI=ENI(10)*(V(IV+1)-V(IV))*ROYV(IYF)*R(IYF)	S0001540
DO 21 IY=IYF,IYLM1	S0001550
IYI=IY+1	S0001560

I=IY+1XINY	S0001570
II=I+1	S0001580
IF=I+IY	S0001590
III=II+1	S0001600
IV=I-III	S0001610
IW=II+1	S0001620
IV=IY+1XINY1	S0001630
IF=IY+I(ONST	S0001640
EMUM=EMU(1)+EMU(III)	S0001650
EMUE=EMUM+EMU(II)+EMU(III)	S0001660
EMUW=EMUM+EMU(II)+EMU(INW)	S0001670
STERM=(EMUE*(U(IN)-U(I))-EMUW*(U(INW)-U(IW)))*QRSXG*RDYG(IYP1)	S0001680
EDVDYS=EDVDYN	S0001690
EDVDYN=EMU(INI)*(V(IV+1)-V(IV))*RDYV(IYP1)*R(IYP1)	S0001700
STERM=STERM+(EDVDYN-EDVDYS)/AREAE(IY)	S0001710
VOLUME=0.5*(VOL(1)+VOL(IN))	S0001720
SU(IY)=STERM*VOLUME+AREAN(I)*(P(IP)-P(IP+1))	S0001730
SP(IY)=-EMUM*VOLUME/RVSQ(IY)	S0001740
C----- INERTIAL UNDER-RELAXATION -----	S0001750
AFAC=0.0	S0001760
ASU=AFAC*ABS(SU(IY))	S0001770
AFAC1=ASU/(ABS(V(IV))+TINY)	S0001780
AFAT=1.0E3*ASU	S0001790
AFAC2=AFAC1*(AFAC1,AFAT)	S0001800
SU(IY)=SU(IY)+AFAC2*V(IV)	S0001810
SP(IY)=SP(IY)-AFAC2	S0001820
21 CONTINUE	S0001830
RETURN	S0001840
22 DO 23 IY=IYF,IYLM1	S0001850
I=IY+1XINY	S0001860
II=I+1	S0001870
IF=IY+I(ONST	S0001880
SU(IY)=AREAN(I)*(P(IP)-P(IP+1))	S0001890
23 SP(IY)=-.25*(EMU(I)+EMU(IN))*(VOL(I)+VOL(IN))/RVSQ(IY)	S0001900
RETURN	S0001910
25 DO 26 IY=IYF,IYLM1	S0001920
SU(IY)=0.0	S0001930
26 SP(IY)=-BIG	S0001940
RETURN	S0001950
C-----	S0001960
CHAPTER 4 4 4 4 4 4 SOURCE TERMS FOR H 4 4 4 4 4 4 4 4	S0001970
C-----	S0001980
40 CONTINUE	S0001990
DO 460 IY=IYF,IYL	S0002000
SU(IY)=0.0	S0002010
460 SP(IY)=0.0	S0002020
C	S0002030
IF(IX.EQ.OX) GO TO 430	S0002040
I=IYN+1XINY	S0002050
IS=I-1	S0002060
IN=I+1	S0002070
IF=I+IY	S0002080

IX=I-IY	S0002090
ISW=IX-1	S0002100
IW=IX+1	S0002110
IWAL=IX+IX-1	S0002120
IWALS=IX-1	S0002130
IWALL=IX+IX	S0002140
IWALW=IX-IX	S0002150
IWALSW=IWALW-1	S0002160
GRAD13=0.0	S0002170
GRAD14=0.0	S0002180
IF (IX.GT.IXW) GO TO 415	S0002190
AE(IYW)=0.0	S0002200
AW(IYW)=0.0	S0002210
AS(IYW)=0.0	S0002220
AW(IYW)=0.0	S0002230
AS(IYWP1)=0.0	S0002240
AW(IYWP1)=0.0	S0002250
H11=ST11*RH0(TS)*ABS(0.5*(U(IS)+U(ISW)))*CMIX	S0002260
RU11=SGG(IX)/(1.0/(R11+H11)+ALNR11/COND)	S0002270
Q11=RU11*TEM(IS)	S0002280
H10=ST10*RH0(IN)*ABS(0.5*(U(IN)+U(INW)))*CMIX	S0002290
RU10=SGG(IX)/(1.0/(R10+H10)+ALNR10/COND)	S0002300
Q10=RU10*TEM(IN)	S0002310
IF (IX.EQ.IXW) GO TO 401	S0002320
IF (IX.EQ.IXW) GO TO 405	S0002330
CAREA=CONJ*ARFAE(IYW)	S0002340
GAMAE=CAREA*RDXG(IXP1)	S0002350
GAMAW=CAREA*RDXG(IX)	S0002360
QCOND1=GAMAE+GAMAW	S0002370
QCOND2=GAMAE*TEM(IE)+GAMAW*TEM(IW)	S0002380
GO TO 410	S0002390
401 GAMAE=CONJ*ARFAE(IYW)*RDXG(IXP1)	S0002400
QCOND1=GAMAE	S0002410
QCOND2=GAMAE*TEM(IE)	S0002420
GO TO 410	S0002430
405 GAMAW=CONJ*ARFAE(IYW)*RDXG(IX)	S0002440
QCOND1=GAMAW	S0002450
QCOND2=GAMAW*TEM(IW)	S0002460
410 CONTINUE	S0002470
GRAD11=SIGMA*(TEM(IWAL)+TEM(I))*(TEM(IWAL)**2+TEM(I)**2)	S0002480
1/(1.0/(CAREA*(I)*EMIS10)+REMI/AREAN(IWALS))	S0002490
GRAD13=GRAD11	S0002500
GRAD14=GRAD11*TEM(I)	S0002510
SU(IYWP1)=RU11*TEM(I)-Q11	S0002520
SU(IYW)=QCOND2+GRAD11*TEM(IWAL)+Q11+Q10	S0002530
SP(IYW)=QCOND1-GRAD11-RU11-RU10	S0002540
SU(IYWP1)=RU10*TEM(I)-Q10	S0002550
415 H2I=ST2I*RH0(IWALS)*ABS(0.5*(U(IWALS)+U(IWALSW)))*CMIX	S0002560
RU2I=SGG(IX)/(1.0/(R2I+H2I)+ALNR2I/COND)	S0002570
Q2I=RU2I*TEM(IWALS)	S0002580
H20=ST20*RH0(INF)*ABS(UINF)*CMIX	S0002590
	S0002600

RU20= SXG(IX)/(1.0/(R20*H20)+ALH R20/COND)	S0002610
Q20=RU20*TINF	S0002620
IF (IX.EQ.2) GO TO 416	S0002630
CAREA=COND*WAREA	S0002640
GAMAE=CAREA*RDYG(IXP1)	S0002650
GAMAW=CAREA*RDYG(IX)	S0002660
QCOND1=GAMAE+GAMAW	S0002670
QCOND2=GAMAE*TEM(IWALE)+GAMAW*TEM(IWALW)	S0002680
GO TO 420	S0002690
416 GAMAE=COND*WAREA*RDYG(IXP1)	S0002700
QCOND1=GAMAE	S0002710
QCOND2=GAMAE*TEM(IE)	S0002720
420 QRAD01=SIGMA*SXG(IX)*R20*EMIS20*(TINF+TEM(IWAL))	S0002730
1*(TINF**2+TEM(IWAL)**2)	S0002740
SU(NY)=QCOND2+QRAD01+QRAD01*TINF+Q21+Q20	S0002750
SP(NY)=-QCOND1-QRAD01-QRAD01-RU21-RU20	S0002760
SU(NYM1)=RU21*TEM(IWAL)-Q21	S0002770
C	S0002780
IF (IX.NE.IXMI) RETURN	S0002790
HEL3C=0.5*EL3/COND	S0002800
DO 425 IY=2,NYM1	S0002810
I=IY+IX1NY	S0002820
IE=I+NY	S0002830
IV=IY+IX1NY1	S0002840
IVS=IV-1	S0002850
HXI=STXI*RHO(I)*ABS(0.5*(V(IV)+V(IVS)))*CMIX	S0002860
UXI=AREAE(IY)/(1.0/HXI+HEL3C)	S0002870
QXI=UXI*(TEM(I)-TEM(IE))	S0002880
425 SU(IY)=SU(IY)-QXI	S0002890
RETURN	S0002900
430 DO 435 IY=IYF,IYL	S0002910
I=IY+IX1NY	S0002920
IV=IY+IX1NY1	S0002930
IW=I-NY	S0002940
IVW=IV-NYM1	S0002950
IVSW=IVW-1	S0002960
IN=I+1	S0002970
IS=I-1	S0002980
CONDL=COND*EL3	S0002990
IF (IY.EQ.IY) GO TO 431	S0003000
HXI=STXI*RHO(IW)*ABS(0.5*(V(IVW)+V(IVSW)))*CMIX	S0003010
UXI=AREAE(IY)/(1.0/HXI+HEL3C)	S0003020
QXI=UXI*TEM(IW)	S0003030
GAMAI=CONDL/ALOG(R(IY+1)/R(IY))	S0003040
GO TO 432	S0003050
431 UX1=0.0	S0003060
QXI=0.0	S0003070
GAMAI=0.0	S0003080
HXU=STXU*RHOINF*ABS(VINF)*CMIX	S0003090
UXU=WAREA/(1.0/HXU+HEL3C)	S0003100
GO TO 436	S0003110
432 HXU=STXU*RHOINF*ABS(VINF)*CMIX	S0003120

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      UXO=AREAE(IY)/(1.0/HXO+HXL3G)
436 QXO=UXO*TINF
      IF(IY.EQ.2) GO TO 433
      GAMAS=CONDL/ALOG(R(IY)/R(IY-1))
      GO TO 434
433 GAMAS=0.0
434 AH(IY)=GAMAH
      AS(IY)=GAMAS
      QRAD1=SIGMA*AREAE(IY)*(EMISXI+EMISXU)*(TINF+TEM(I))
      1 *(TINF**2+TEM(I)**2)
      AW(IY)=0.0
      SU(IY)=QRAD1*TINF+QXI+QXO
435 SP(IY)=-QRAD1-UXI-UXO
      GAMAW=COND*WAREA*RDWG(IX)
      SU(NY)=SU(NY)+GAMAW*TEM(IX1NY)
      SP(NY)=SP(NY)-GAMAW
      H2O=ST20*RHOINF*ABS(UINF)*CMIX
      RU20=EL3/(1.0/(R20*H2O)+ALNR20/COND)
      Q2U=RU20*TINF
      SU(NY)=SU(NY)+Q2U
      SP(NY)=SP(NY)-RU20
      RETURN
C-----S0003130
CHAPTER 5 5 5 5 5 SOURCE TERMS FOR MIXTURE FRACTION 5 5 5 5 S0003140
C-----S0003150
50 DO 52 IY=IYF,IYL
      SU(IY)=0.0
      S0003160
52 SP(IY)=0.0
      RETURN
      S0003170
C-----S0003180
CHAPTER 6 6 6 6 6 6 6 SOURCE TERMS FOR FUEL 6 6 6 6 6 6 S0003190
C-----S0003200
60 T1=PREEXP*PRESS**2
      DO 62 IY=IYF,IYL
      I=IY+IX1NY
      FUBRNT=AMAX1(0.0,(FM(I)-FSTOIC)*RFS7M)
      FULX=FUE(I)-FUBRNT
      IF (FUEX.GT.0.0) GO TO 61
      SP(IY)=-BIG
      GO TO 62
      S0003210
61 FOX=AMAX1(TINY,STOICH*(FUE(I)-(FM(I)-FSTOIC)*RFS7M))
      SP(IY)=-T1*EXP(-ARRCON/TEM(I))*VOL(I)*FOX*FUE(I)/FUEX
      S0003220
62 SU(IY)=-SP(IY)*FUBRNT
      RETURN
      S0003230
C-----S0003240
CHAPTER 7 7 7 7 7 7 7 SOURCE TERMS FOR P 7 7 7 7 7 7 7 S0003250
C-----S0003260
90 ERROR=0.0
      IF (IX.EQ.2.AND.INC.EQ.-1) GO TO 93
      DO 92 IY=IYF,IYL
      ERROR MASS SOURCES
      ESMAS=-FLOWN(IY)+FLOWN(IY-1)-FLOWE(IY)+FLOWW(IY)
      S0003270

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      SU(IY)=ESMASS
      SP(IY)=0.0
92  ERROR=ERROR+ABS(ESMASS)
      IF (IX.NE.NXM1.OR.INC.NE.1) GO TO 95
      SU(IYL)=0.0
      SP(IYL)=-BIG
      GO TO 95
C-----OUTLET BOUNDARY - UNIFORM PRESSURE ASSUMED.
93  DO 94 IY=IYF,IYL
      SU(IY)=0.0
94  SP(IY)=-BIG
95  RSLINE(IX,JPP)=ERROR/MSREF(JPP)
      AKSL(IX,JPP)=ABS(RSLINE(IX,JPP))
      RETURN
      END

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S0003660
S0003670
S0003680
S0003690
S0003700
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S0003720
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S0003740
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S0003770
S0003780
S0003790

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SUBROUTINE WALL(11,STERM,STERM1,IY,JPHI)
COMMON/044/ U(480),V(475),H(500),FH(500),FUE(500),FS(500,15),
1  IP(20),TFM(500),P(414),RHO(500),EMU(500),
1  IAG(25),IXU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),
2  STORE(25),SXG(25),SXU(25),X(25),XU(25),
3  A(20),AE(20),AH(20),AREAE(20),AS(20),ASNIP(20),AW(20),B(20),
4  CSNIP(20),C(20),CSNIP(20),DIFE(20),DIFEE(20),DIFN(20),
5  DIFNE(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),
6  FLOWE(20),FLOWEE(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),
7  RXYG(20),RXYV(20),RSYG(20),RSYV(20),RV(20),RVCB(20),RVSG(20),
8  SP(20),SU(20),SYG(20),SYV(20),Y(20),YV(20),AEDDX(500),
9  ANDDY(500),ARFAH(500),VOL(500),
X  ARSL(25,25),PREF(25),PRL(25),PRT(25),RSLINE(25,25),
1  ICW(25),ILAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),
2  KSRF(25),RSSUM(25),TITLE(25)
DIMENSION DIFNW(20),DIFWW(20),F(11889),FLOWNW(20),FLOWWW(20)
EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),
1  FLOWFE(1)),(DIFNW(1),DIFNE(1)),(DIFWW(1),DIFEE(1))
COMMON/COMB/
1  AK,ARREF,ABIG,CHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,
2  EPST,EPAT,EWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,
3  FSTOIM,FUB,FUC,HFU,HW,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,
4  ISWEP,IX,IXMON,IXREF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,
5  IX1NY1,IX2NYU,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,
6  IYREF,IYW,IYWM1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,
7  JS1,JS,JTEM,JU,JV,KASE,KINPRI,KLT,KRAD,KRHOMU,KSWEET,KTEST,
8  LABPHI,LSWEEP,NSOLVE,NTDMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,
9  NXM2,NYYC,NXYP,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OXB,OXE,PJAY,
X  PRELXP,PRESS,RELAXP,RF,RFSTH,RSCHK,RSMAX,R1I,R10,R21,R20,
1  STOICH,TB,TC,TINY,TMAX,TMIN,UB,UC,WMIX
DATA SHALF/0.04/
KWALL=2-1/11
I2=I1+3-2*KWALL
I3=I1+2-KWALL
IF (IY,EL,0) GO TO 10000
I=I2+IX1NY
IF (JPHI,PQ,JH) GO TO 10
RETURN
10 I=I2+IX1NYU
RUREF=RHO(I)*ABS(U(I))
RE=RUREF*HYG(I3)/EMUREF
IF (KLT,LO,1) GO TO 19
IF (RE,LT,132.25) GO TO 19
ER=RE*EWALL
ARGMIN=11.5*EWALL
DO 17 N1=1,11
SHALF1=SHALF
ARG=ER*SHALF
IF (ARG,LT,ARGMIN) GO TO 19
SHALF=AR/ALOG(ARG)

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 WA000490
 WA000500
 WA000510
 WA000520

IF (ABS(SHALF-SHALF1).LT.0.0001) GO TO 18	WA000530
17 CONTINUE	WA000540
18 S=SHALF**2	WA000550
STERM1=S*(I2)*RURCF*SXU(IXU)	WA000560
RETURN	WA000570
19 STERM1=(MURCF*SXU(IXU)*R(I1)*RDYG(I3)	WA000580
RETURN	WA000590
10000 I=IY+IXINY	WA000600
IF (OPHI.EQ.OV) GO TO 200	WA000610
RETURN	WA000620
200 RURCF=RHO(I)*ABS(V(I))	WA000630
RI=RURCF*DXG(I3)/EMURCF	WA000640
IF (KLT.EQ.1) GO TO 290	WA000650
IF (RE.LT.132.25) GO TO 290	WA000660
ET=RE*EWALL	WA000670
ARGMIN=11.5*EWALL	WA000680
LC 270 IIT=1+11	WA000690
SHALF1=SHALF	WA000700
ARG=LR*SHALF	WA000710
IF (ARG.LT.ARGMIN) GO TO 290	WA000720
SHALF=ARG/ALOG(ARG)	WA000730
IF (ABS(SHALF-SHALF1).LT.0.0001) GO TO 280	WA000740
270 CONTINUE	WA000750
280 S=SHALF**2	WA000760
STERM1=S*RURCF*SYV(IY)*RV(IY)	WA000770
RETURN	WA000780
290 STERM1=(MURCF*SYV(IY)*RV(IY)*RDXG(I3)	WA000790
RETURN	WA000800
END	WA000810

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SUBROUTINE CHEM(KGOTO)	CH000010
COMMON/COA/ H(400),V(475),H(500),FM(500),FUE(500),FS(500,15),	CH000020
1 PP(20),CFM(500),P(414),RHO(500),EMU(500),	CH000030
1 LXG(25),RXU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),	CH000040
2 STORL(25),SXG(25),SXU(25),X(25),XU(25),	CH000050
4 A(24),AF(20),AH(20),AREAE(20),AS(20),ASNIP(20),AW(20),B(20),	CH000060
4 LSNIP(20),C(20),CSHIP(20),DIFE(20),DIFEE(20),DIFN(20),	CH000070
5 LIFNE(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),	CH000080
6 FLOWE(20),FLOWEE(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),	CH000090
7 PDYS(25),RDYV(20),RSYG(20),RSYV(20),PV(20),RVCB(20),RVSQ(20),	CH000100
8 SP(20),SH(20),SYG(20),SYV(20),Y(20),YV(20),AEDDX(500),	CH000110
9 ANDDY(500),AREAN(500),VOL(500),	CH000120
X ARSL(25,25),PREFF(25),PRL(25),PRT(25),RSLINE(25,25),	CH000130
1 IEW(25),JLAST(25),IMON(25),IXNY(25),JZERO(25),KSOLVE(25),	CH000140
2 RSREF(25),RSSUM(25),TITLE(25)	CH000150
DIMENSION DIFHW(20),DIFFW(20),F(11889),FLOWNW(20),FLOWWW(20)	CH000160
EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),	CH000170
1 FLOWEE(1)),(DIFHW(1),DIFNE(1)),(DIFFW(1),DIFEE(1))	CH000180
COMMON/COMB/	CH000190
1 AK,APPROX,BIG,CHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,	CH000200
2 EPSI,ERAT,EWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,	CH000210
3 ISTM,IFUB,FUC,HFU,HV,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,	CH000220
4 JSWEEP,IX,IXMON,IXPREF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,	CH000230
5 IX1NY1,IX2NY1,IX2NY2,IY,IYF1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,	CH000240
6 IYPREF,IYU,IYWM1,IYWP1,JEMU,JFH,JFUE,JH,JLAST,JP,JPP,JRHO,	CH000250
7 JS1,JS2,JTEM,JH,JV,KASE,KINPRI,KLT,KRAD,KRHOMU,KSWEET,KTEST,	CH000260
8 LABPHI,LSWEEP,NSOLVE,NTDMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,	CH000270
9 NXM2,OXYC,NXYP,NXYU,NXYV,NY,NYMAX,NYN1,NYM2,OXB,OXE,PJAY,	CH000280
X PREEXP,PRESS,RELAXP,RF,RFSTM,RSCHK,RSMAX,R1I,R1O,R2I,R2O,	CH000290
1 STOICH,TK,TC,TINY,TMAX,TMIN,UB,UC,WM1X	CH000300
LOGICAL CONVG	CH000310
COMMON /INDEX/ IDC0,IDC02,IDF,IDH,IDH2,IDH20,IDO,IDOH,IDO2,IDN,	CH000320
1 IDH3,IDH02,IDH2,IDH20,IEQUIL,IHCP5,IPR,JJ,KNTCS,HA,NLM,	CH000330
2 I,S,USE1,USE2,NSK,NSM,NS1,NS2,ID(4,15)	CH000340
3/PARAMS/ CONVG,ENV,CPSS,GASCON,IDEBUG,ITMAX,PA,SM,TINYK,TK,TLN,TNY	CH000350
5/SPECES/ASUM(20,5),CPSUM,HSUM,HO(14),SMW(14),SO(14),S1(14),	CH000360
6 S2(14),Z(2,7,14)	CH000370
7/CEWTL/AC1,AC2,AC3,AC4,AH1,AH2,AH3,AH4,ASM1,ASM2,ASM3,ASM4,	CH000380
8 AS1(4,7,2),HDTV,HMAX,HMIN,PEXP(7)	CH000390
9/PEACTS/BX(15),BX2(15),TACT(15),TACT2(15),TEN(15),TEN2(15)	CH000400
-----	CH000410
CHAPTER 1	CH000420
-----	CH000430
ENTRY TMAP	CH000440
SP1=1.0+STOICH	CH000450
IHCP5=2	CH000460
NS1=IDH2	CH000470
NS2=IDO2	CH000480
IF(KNTCS.EQ.0) NS1=1	CH000490
DO 115 JY=2,NYM1	CH000500
I=IY+IXJHY	CH000510
	CH000520

[illegible]

RETURN	CH001050
C-----	CH001060
CHAPTER 3	CH001070
C-----	CH001080
ENTRY EQUI	CH001090
RHDIFF=1.0/(HMAX-HMIN)	CH001100
PRATIO=PRESS*0.5E-5	CH001110
DO 325 IY=IYF,IYL	CH001120
I=IY+IX1NY	CH001130
SUM=FS(I,1DF)+FS(I,ID02)	CH001140
FPR=FS(I,TPR)	CH001150
HPR=(AH1+(AH2+(AH3+AH4*TEM(I))*TEM(I))*TEM(I))*GASCON	CH001160
HPR=AMAX1(HPR,HMIN)	CH001170
HPR=AMIN1(HPR,HMAX)	CH001180
KK=1	CH001190
IF (HPR.GT.HDIV) KK=2	CH001200
HPR=(HPR-HMIN)*RHDIFF	CH001210
DO 305 II=NSE1,NSE2	CH001220
LL=II-NSE1+1	CH001230
FSII=AS1(1,LL,KK)+(AS1(2,LL,KK)+(AS1(3,LL,KK)+AS1(4,LL,KK)	CH001240
1 *HPR)*HPR)*HPR	CH001250
FS(I,II)=FPR*EXP(FSII)*PRATIO**PEXP(LL)	CH001260
305 SUM=SUM+FS(I,II)	CH001270
IF (KUTCS.EQ.0) FS(I,IDN2)=AMIN1(1.0-SUM,1.0-0XC)	CH001280
325 CONTINUE	CH001290
IF (KTEST.EQ.1) RETURN	CH001300
DO 330 II=NSE1,MSL2	CH001310
LAPHT=II+JS1-1	CH001320
330 CALL TEST(21)	CH001330
RETURN	CH001340
C-----	CH001350
CHAPTER 4	CH001360
C-----	CH001370
ENTRY KINF	CH001380
PA=PRESS	CH001390
IF (ISWEEP.EQ.KSWEEP) GO TO 484	CH001400
IF (ISWEEP.EQ.(KSWEEP+1)) GO TO 485	CH001410
GO TO 495	CH001420
485 IF (IX.GT.IXW) GO TO 495	CH001430
484 INCHY=INC*NY	CH001440
DO 482 ISP=1,NSK	CH001450
DO 482 IY=IYF,IYL	CH001460
I=IY+IX1NY	CH001470
IUP=I-INCHY	CH001480
IUN=I+INCHY	CH001490
FS(I,ISP)=FS(IUP,ISP)	CH001500
482 FS(IUN,ISP)=FS(I,ISP)	CH001510
495 DO 487 IY=IYF,IYL	CH001520
I=IY+IX1NY	CH001530
IF=I+1	CH001540
IS=I-1	CH001550
II=I+NY	CH001560

IX=1-IY	CH001570
LEV=AL(IY)+AW(IY)+AH(IY)+AS(IY)	CH001580
DO 486 ISP=1,NSE2	CH001590
486 S2(ISP)=FS(I,ISP)/SMW(ISP)	CH001600
TK=LEW(I)	CH001610
DO 488 ISP=1,NSK	CH001620
S1(ISP)=(AH(IY)+FS(IN,ISP)+AS(IY)*FS(IS,ISP)+AW(IY)*FS(IW,ISP)	CH001630
1 +AE(IY)*FS(IF,ISP))/(LEV*SMW(ISP))	CH001640
488 S2(ISP)=FS(I,ISP)/SMW(ISP)	CH001650
PWR=LEWRAT-0.10	CH001660
LEV=LEV/(VOL(I))*PWR	CH001670
IF(TK.LE.550.0) GO TO 400	CH001680
CALL SPEC	CH001690
IF(CONVC) GO TO 410	CH001700
WRITE(6,491) IX,IY	CH001710
491 FORMAT (10X,68HCHEMICAL KINETICS SOLUTION FAILED...AVG INLET PROPE	CH001720
RTIES RETURNED /10X,6HAT IX=,I3.9H,AND, IY=,I3/)	CH001730
400 DO 402 ISP=1,NSK	CH001740
402 S2(ISP)=S1(ISP)	CH001750
410 SUM=0.0	CH001760
DO 489 ISP=1,NSE2	CH001770
489 SUM=SUM+S2(ISP)*SMW(ISP)	CH001780
DO 490 ISP=1,NSK	CH001790
490 FS(I,ISP)=S2(ISP)*SMW(ISP)/SUM	CH001800
SUM=0.0	CH001810
DO 493 ISP=1,NSE2	CH001820
493 SUM=SUM+FS(I,ISP)	CH001830
FS(I,IDW2)=AMTH1(1.0+FS(I,IDW2)-SUM,1.0-0XC)	CH001840
487 CONTINUE	CH001850
RETURN	CH001860
END	CH001870

SUBROUTINE SPECC	SP000010
LOGICAL CONVG	SP000020
DOUBLE PRECISION A,X,Y	SP000030
COMMON /INDEX/ IDC0,IDC02,IDF,IDH,IDH2,IDH20,IDO,IDOH,IDO2,IDN,	SP000040
1 IDN0,1,IND2,IND2,IND20,IEQUIL,IHCPS,IPR,JJ,KNTCS,NA,NLM,	SP000050
2 IS,ISE1,ISE2,NSK,NSM,NS1,NS2,IO(4,15)	SP000060
3/PARAMS/ COIVG,EMV,EPSS,GASCON,IDEBUG,ITMAX,PA,SM,TINYK,TK,TLN,TNY	SP000070
5/SPECES/ASUB(20,3),CPSUM,HSUM,H0(14),SMW(14),SQ(14),S1(14),	SP000080
6 S2(14),Z(2,7,14)	SP000090
7/LEQUIL/AC1,AC2,AC3,AC4,AH1,AH2,AH3,AH4,ASM1,ASM2,ASM3,ASM4,	SP000100
8 AS1(4,7,2),H0IV,HMAX,HMIN,PEXP(7)	SP000110
9/REALTS/DX(15),RX2(15),TACT(15),TACT2(15),TEN(15),TEN2(15)	SP000120
COMMON/ELMNTS/ATOM(3,7),BO(7)	SP000130
1 /STOCHU/ AL(7,14)	SP000140
2 /MATRIX/ A(14,15),X(15),Y(15)	SP000150
C-----	SP000160
CHAPTER 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	SP000170
C-----	SP000180
CONVG=.FALSE.	SP000190
SM=0.0	SP000200
DO 100 IS=1,NS	SP000210
S2(IS)=AMAX1(S2(IS),TINYK)	SP000220
SM=SM+S2(IS)	SP000230
Y(IS)=ALOG(S2(IS))	SP000240
100 X(IS)=0.0	SP000250
X(NS)=0.0	SP000260
Y(NS)=ALOG(SM)	SP000270
IMAT=NSK	SP000280
KMAT=IMAT+1	SP000290
C-----	SP000300
CHAPTER 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	SP000310
C-----	SP000320
DO 200 ITER=1,ITMAX	SP000330
CALL CALC	SP000340
IF (IDEBUS.EQ.0) GO TO 220	SP000350
WRITE (6,221)	SP000360
221 FORMAT (100,10X,38H ELEMENTS A(I,K) OF CORRECTION MATRIX /)	SP000370
DO 222 K=1,IMAT	SP000380
222 WRITE (6,223) (A(K,I),I=1,KMAT)	SP000390
223 FORMAT (1H,1P11E10.2)	SP000400
220 DO 230 NN=1,IMAT	SP000410
K=NN+1	SP000420
DTM1=1.0/A(NN,NN)	SP000430
DO 225 J=K,KMAT	SP000440
225 A(NN,J)=A(NN,J)*DTM1	SP000450
IF (K.EQ.KMAT) GO TO 230	SP000460
DO 226 I=K,IMAT	SP000470
DO 226 J=K,KMAT	SP000480
226 A(I,J)=A(I,J)-A(I,NN)*A(NN,J)	SP000490
230 CONTINUE	SP000500
K=IMAT	SP000510
	SP000520

235 J=K+1	SP000530
SUM=0.0	SP000540
X(K)=0.0	SP000550
IF (IMAT,1,T,J) GO TO 240	SP000560
DO 236 I=1,IMAT	SP000570
236 SUM=SUM+A(K,I)*X(I)	SP000580
240 X(K)=A(1,IMAT)-SUM	SP000590
K=K+1	SP000600
IF (K,NL,4) GO TO 235	SP000610
C-----	SP000620
CHAPTER 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3	SP000630
C-----	SP000640
ETA1=1.	SP000650
SUM=TINYK	SP000660
DO 300 IS=1,NSK	SP000670
IF (X(IS).LE.0.0) GO TO 300	SP000680
SUM=AMAX1(X(IS),SUM)	SP000690
IF (S2(IS)/SUM.LE.1.E-8)	SP000700
1 ETA1=AMIN1(ABS(Y(NSM)-Y(IS)-9.212)/X(IS),ETA1)	SP000710
300 CONTINUE	SP000720
ETA=AMIN1(ETA1,2.0/SUM)	SP000730
C-----	SP000740
CHAPTER 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4	SP000750
C-----	SP000760
DO 400 IS=1,NSK	SP000770
Y(IS)=Y(IS)+ETA*X(IS)	SP000780
Y(IS)=AMAX1(Y(IS),TINY)	SP000790
400 S2(IS)=EXP(Y(IS))	SP000800
IF (IDEB,6,NC) WRITE(6,410) ITER,ETA,(ASUB(K,1),S2(K),Y(K),X(K),	SP000810
1 E=1,NS)	SP000820
410 FORMAT(10H,6HITER =,I3,5X,5HETA =,1PE10.3//17X,2HS2,12X,5HLOGS2,	SP000830
1 8X,5HD(LOGS2)//(5X,A4,1P3E15.6))	SP000840
C-----	SP000850
CHAPTER 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	SP000860
C-----	SP000870
IF (ETA.LT.1.) GO TO 200	SP000880
DO 510 IS=1,NSK	SP000890
IF (S2(IS).LE.TINYK*1.001) GO TO 510	SP000900
IF (ABS(X(IS)).GT.EPSS) GO TO 200	SP000910
510 CONTINUE	SP000920
CONVG=.TRUE.	SP000930
RETURN	SP000940
200 CONTINUE	SP000950
RETURN	SP000960
END	SP000970

```

SUBROUTINE CALL
LOGICAL CONVG
DOUBLE PRECISION A,X,Y
COMMON /INDEX/ IDCO, IDCO2, IDI, IDH, IDH2, IDH20, IDO, IDOH, IDO2, IDN,
1 IDH0, IDH2, IDH2, IDH20, IEQUIL, IHCP5, IPP, JJ, KNTCS, NA, NLM,
2 NS, NS1, NS2, NSK, NSM, NS1, NS2, ID(4,15)
3 /APAS/ LOHVG, FHV, EPSS, GASCON, IDEBUG, ITMAX, PA, SM, TINYK, TK, TLN, TNY
5 /SPECIS/ AUB(20,3), CP5UM, HSUM, HO(14), SMW(14), SO(14), S1(14),
6 S2(14), Z(2,7,14)
7 /EQUIL/ AC1, AC2, AC3, AC4, AH1, AH2, AH3, AH4, ASM1, ASM2, ASM3, ASM4,
8 AS1(4,7,2), HOIV, HMAX, HMIN, PEXP(7)
9 /EACIS/ BX(15), EX2(15), TACT(15), TACT2(15), TEN(15), TEN2(15)
COMMON /IL-NTS/ ATOM(3,7), BO(7)
1 /STOCH/ AL(7,14)
2 /MATRIX/ A(14,15), X(15), Y(15)
C-----
CHAPTER 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 CA000170
C-----
H5K1=H5I+1
DO 10 I=1,NS
DO 10 K=1,NA
10 A(I,K)=0.0
RHSI=PAZ/(GASCON*TK)
TKINV=1.0/TK
RHPQ=RHSI/SM
RHSQ=RHPQ*RHOQ
RHSMP=RHSI*RHOQ
RHSMSQ=RHSMP*RHSQ
C-----
CHAPTER 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 CA000300
C-----
DO 200 J=1,JJ
R1=B*(J)*EXP(-TACT(J)*TKINV)*TK**TEN(J)
R2=G*2(J)*EXP(-TACT2(J)*TKINV)*TK**TEN2(J)
I=ID(1,J)
K=ID(2,J)
M=ID(3,J)
N=ID(4,J)
IF (K.EQ.0) GO TO 20
IF (M.EQ.0) GO TO 30
MODE=1
R1=(RHSQ+S2(I))*(R1*S2(K))
R2=(RHSQ+S2(M))*(R2*S2(N))
GO TO 40
20 MODE=2
R1=RHSMP+S2(I)*R1*S2(K)
R2=RHSMP+S2(M)*R2*S2(N)
GO TO 40
30 MODE=3
R1=RHSMP+S2(I)*R1*S2(K)
R2=RHSMP+S2(M)*R2*S2(N)
C-----

```

40	TM1=K1-K2	CA000530
	A(I,I)=A(I,I)+R1	CA000540
	A(M,I)=A(I,I)-R1	CA000550
	A(I,M)=A(I,M)+P2	CA000560
	A(M,M)=A(I,M)+P2	CA000570
	A(I,HA)=A(I,HA)-TM1	CA000580
	A(M,HA)=A(M,HA)+TM1	CA000590
	IF (MODI.FQ.3) GO TO 50	CA000600
	A(H,I)=A(H,I)-R1	CA000610
	A(H,M)=A(H,M)+P2	CA000620
	A(I,H)=A(I,H)-R2	CA000630
	A(H,H)=A(H,H)+R2	CA000640
	A(H,I)=A(H,I)+P2	CA000650
	A(H,HA)=A(H,HA)+TM1	CA000660
	IF (MODI.FQ.2) GO TO 200	CA000670
50	A(K,I)=A(K,I)+P1	CA000680
	A(I,K)=A(I,K)+R1	CA000690
	A(K,K)=A(K,K)+R1	CA000700
	A(M,K)=A(I,K)-R1	CA000710
	A(K,M)=A(K,M)-R2	CA000720
	A(K,HA)=A(K,HA)-TM1	CA000730
	IF (MODI.FQ.3) GO TO 200	CA000740
	A(H,K)=A(H,K)+P1	CA000750
	A(K,H)=A(K,H)-R2	CA000760
200	CONTINUE	CA000770
C-----C-----		CA000780
CHAPTER	3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3	CA000790
C-----C-----		CA000800
	DO 300 IS=1,NSK	CA000810
	A(IS,IS)=A(IS,IS)+ENV*S2(IS)	CA000820
300	A(IS,NSK1)=A(IS,HA)+ENV*(S1(IS)-S2(IS))	CA000830
	RETURN	CA000840
	END	CA000850

ORIGINAL PAGE IS
OF POOR QUALITY

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SUBROUTINE CONST(RGOTO)
COMMON/CPH/ U(480),V(475),H(500),FM(500),FUE(500),FS(500,15),
1 TP(20),TM(500),P(414),RHO(500),LMU(500),
1 XG(25),XU(25),KOUNT(25),RXG(25),RXU(25),RSXG(25),RSXU(25),
2 STOR(25),SXG(25),SXU(25),X(25),XU(25),
3 A(20),AE(20),AU(20),AREAC(20),AS(20),ASNIP(20),AW(20),D(20),
4 LSHIP(20),C(20),CSHIP(20),DIFE(20),DIFEE(20),DIFN(20),
5 DIFE(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),
6 FLOWL(20),FLOWEC(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),
7 RGY(20),RGYV(20),RSYG(20),RSYV(20),RV(20),RVCB(20),RVSQ(20),
8 SP(20),SQ(20),SYG(20),SYV(20),Y(20),YV(20),AEDDX(500),
9 ANDDY(500),ARFAN(500),VOL(500),
X ARSI(25,25),PRFF(25),PRL(25),PRT(25),RSLINE(25,25),
1 IEW(25),ILAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),
2 RSREF(25),RSSUM(25),TITLE(25)
DIMENSION DIFNW(20),DIFWW(20),F(11809),FLOWNW(20),FLOWWW(20)
EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),
1 FLOWFE(1)),(DIFNW(1),DIFNE(1)),(DIFWW(1),DIFEE(1))
COMMON/COMB/
1 AK,ABRCOH,BLS,CHECK,CHIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,
2 LPST,ENRAT,EWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,
3 FSTOIM,FUB,FUC,HF,U,HW,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,
4 ISWEP,IX,IXMON,IXPREF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,
5 IX1NY1,IX2NY1,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,
6 IYPRF,IYW,IYWM1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,
7 JS1,JS2,JTEM,JU,JV,KASE,KINPRI,KLT,KRAD,KRHOMU,KSWEPT,KTEST,
8 LAHMI,LSWEEP,NSOLVE,NTDMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,
9 NXMP,NXYG,NXYP,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OX8,OXC,PJAY,
X PRELXP,PRESS,RELAXP,RF,RFSTH,RSCHEK,RSMAX,R1I,R10,R21,R20,
1 STOICH,TA,TC,TINY,TMAX,TMIN,UB,UL,WMIX
C ----- CONSTANTS RELATED TO NX AND NY -----
IF (RGOTO.NE.2) GO TO 3000
NXM1=NX-1
NXM2=NX-2
NYM1=NY-1
NYM2=NY-2
C ----- TOTAL NUMBER OF NODES FOR DIFFERENT VARIABLES
NXYG=NX+NY
NXYP=NX-2+NYMP
NXYU=NX-1+NY
NXYV=NX+NYM1
RTURN
C ----- CONSTANTS RELATED TO VARIABLES -----
3000 IF (RGOTO.NE.3) GO TO 5000
KRHO0U=FSOLVL(JPHO)+KSOLVE(JEMU)
C ----- IZERO,ILAST AND IEW FOR DIFFERENT VARIABLES
IZERO(1)=0
DO 35 J=1,JLAST
IF (J-JU) 310,301,310
310 IF (J-JV) 320,302,320
320 IF (J-JP) 330,303,330

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350	IF (J-JP1) 305,304,305	C0000530
301	IL=IX*YU	C0000540
	ILMAX=(IX*MAX-1)*NYMAX	C0000550
	IEW(J)=NY	C0000560
	GO TO 34	C0000570
302	IL=IX*YV	C0000580
	ILMAX=(IX*MAX+(NYMAX-1)	C0000590
	IL*(J)=Y*1	C0000600
	GO TO 34	C0000610
303	IL=IX*YP	C0000620
	ILMAX=(IX*MAX-2)*(NYMAX-2)	C0000630
	IEW(J)=Y*2	C0000640
	GO TO 34	C0000650
304	IL=NY	C0000660
	ILMAX=NYMAX	C0000670
	IEW(J)=0	C0000680
	GO TO 34	C0000690
305	IL=IX*YB	C0000700
	ILMAX=IX*MAX*NYMAX	C0000710
	IEW(J)=Y	C0000720
34	ILAST(J)=IZERO(J)+IL	C0000730
	IF (J.EQ.ULAST) GO TO 35	C0000740
	JP1=J+1	C0000750
	IZERO(JP1)=IZERO(J)+ILMAX	C0000760
35	CONTINUE	C0000770
	RETURN	C0000780
C----- CONSTANTS RELATED TO CHAP. 5 OF MAIN -----		C0000790
5000	IF (KGO TO.NE.5) RETURN	C0000800
	IPREF=IYPREF-1+(IXPREF-2)*NYM2	C0000810
	DO 56 J=1,ULAST	C0000820
	IF (J.EQ.JPP) GO TO 56	C0000830
	IMON(J)=IYMON+(IXMON-1)*ILW(J)	C0000840
	IF (J.EQ.JP) IMON(J)=IYMON-1+(IXMON-2)*IEW(J)	C0000850
56	CONTINUE	C0000860
	RETURN	C0000870
	END	C0000880

SUBROUTINE GLOM

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C-----GE000350
C-----GE000360
CHAPTER 1 1 1 1 1 1 1 RADII 1 1 1 1 1 1 1 1 1 1GE000370
C-----GE000380
      DO 26 IY=1,NY      GE000390
26  R(IY)=Y(IY)          GE000400
C-----GE000410
CHAPTER 2 2 2 2 2 2 2 CELL-NODE DISTANCES 2 2 2 2 2 2 2 2GE000420
C-----GE000430
C-----GRID-NODE DISTANCESGE000440
      DXG(1)=0.          GE000450
      DYG(1)=0.          GE000460
      DO 30 IX=2,NX      GE000470
      DXG(IX)=X(IX)-X(IX-1)GE000480
30  RDYG(IX)=1./DXG(IX)  GE000490
      DO 31 IY=2,NY      GE000500
      DYG(IY)=Y(IY)-Y(IY-1)GE000510
31  RLDYG(IY)=1./DYG(IY)GE000520

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C----- U-NODE DISTANCES		GE000530
	XU(1)=X(1)	GE000540
	DO 32 I=2, IXM2	GE000550
32	XU(IX)=0.5*(X(IX)+X(IX+1))	GE000560
	XU(IIX+1)=X(IIX)	GE000570
	XU(IIX)=X(IX)	GE000580
	DXU(1)=0.0	GE000590
	DO 33 I=2, IIX+1	GE000600
	DXU(IX)=XU(IX)-XU(IX-1)	GE000610
33	RLDXU(IX)=1./DXU(IX)	GE000620
	DXU(IIX)=0.0	GE000630
C----- V-NODE DISTANCES AND V-CELL BOUNDARY RADII		GE000640
	YV(1)=Y(1)	GE000650
	RV(1)=R(1)	GE000660
	RVCB(1)=R(1)	GE000670
	RVSQ(1)=RV(1)**2	GE000680
	DO 34 IY=2, IYMP	GE000690
	YV(IY)=0.5*(Y(IY)+Y(IY+1))	GE000700
	RV(IY)=0.5*(R(IY)+R(IY+1))	GE000710
	RVSQ(IY)=RV(IY)**2	GE000720
34	RVCB(IY)=R(IY)	GE000730
	RVCB(2)=R(1)	GE000740
	YV(IYM1)=Y(IY)	GE000750
	RV(IYM1)=R(IY)	GE000760
	RVCB(IYM1)=R(IY)	GE000770
	RVSQ(IYM1)=RV(IYM1)**2	GE000780
	YV(IY)=Y(IY)	GE000790
	RV(IY)=R(IY)	GE000800
	RVCB(IY)=R(IY)	GE000810
	RVSQ(IY)=RV(IY)**2	GE000820
	DYV(1)=0.0	GE000830
	DO 35 IY=2, IYMP	GE000840
	DYV(IY)=YV(IY)-YV(IY-1)	GE000850
35	RLDYV(IY)=1./DYV(IY)	GE000860
	DYV(IY)=0.0	GE000870
C-----		GE000880
CHAPTER 3 3 3 3 3 3 CELL DIMENSIONS 3 3 3 3 3 3 3		GE000890
C-----		GE000900
C----- GRID-NODE CELLS		GE000910
	SXG(1)=1.0	GE000920
	DO 40 IX=3, IXXM2	GE000930
40	SXG(IX)=0.5*(DXG(IX)+DXG(IX+1))	GE000940
	SXG(2)=LX*(2)+0.5*DXG(3)	GE000950
	SXG(IXM1)=0.5*(DXG(NXM1)+DXG(NX))	GE000960
	SXG(IIX)=0.0	GE000970
	DO 41 IY=1, IY	GE000980
	IAXIY=(IX-1)*IY	GE000990
	DO 42 IY=1, IY	GE001000
	I=IY+IAXIY	GE001010
49	AREAI(I)=SXG(IX)*RV(IY)	GE001020
	SYG(1)=0.0	GE001030
	DO 41 IY=3, IYMP	GE001040

41	SYG(IY)=0.5*(DYG(IY)+DYG(IY+1))	GE001050
	SYG(NY)=0.0	GE001060
	SYG(2)=SYG(2)+0.5*DYG(3)	GE001070
	SYG(NYM1)=DYG(NY)+0.5*DYG(NYM1)	GE001080
	DO 45 IX=2,NXM1	GE001090
45	RSXG(IX)=1./SXG(IX)	GE001100
	DO 46 IY=2,NYM1	GE001110
	AREAF(IY)=.5*(PV(IY)+RV(IY-1))*SYG(IY)	GE001120
46	RSYG(IY)=1./SYG(IY)	GE001130
	AREAF(1)=0.0	GE001140
	AREAL(NY)=0.0	GE001150
C----- U-VELOCITY CELLS		
	SXU(1)=0.0	GE001160
	DO 42 IX=2,NXM2	GE001170
42	SXU(IX)=X(IX+1)-X(IX)	GE001180
	SXU(2)=SXU(2)+DXG(2)	GE001190
	SXU(NXM1)=SXU(NXM2)+DXG(NX)	GE001200
	SXU(NXM1)=0.0	GE001210
	SXU(NX)=0.0	GE001220
	DO 47 IX=2,NXM2	GE001230
47	RSXU(IX)=1./SXU(IX)	GE001240
C----- V-VELOCITY CELLS		
	SYV(1)=0.0	GE001250
	DO 43 IY=2,NYM2	GE001260
43	SYV(IY)=Y(IY+1)-Y(IY)	GE001270
	SYV(2)=SYV(2)+DYG(2)	GE001280
	SYV(NYM1)=SYV(NYM2)+DYG(NY)	GE001290
	SYV(NYM1)=0.0	GE001300
	SYV(NY)=0.0	GE001310
	DO 48 IY=2,NYM2	GE001320
48	RSYV(IY)=1./SYV(IY)	GE001330
	DO 405 IX=2,NXM1	GE001340
	IX1NY=(IX-1)*NY	GE001350
	IF=1+IX1NY	GE001360
	ARDDY(IF)=AREAL(IF)*RDYG(2)	GE001370
	DO 405 IY=2,NYM1	GE001380
	I=IY+IX1NY	GE001390
	AREDDX(1)=AREAF(IY)*RDXG(IX+1)	GE001400
	ARDDY(1)=AREAL(1)*RDYG(IY+1)	GE001410
405	VOL(1)=AREAF(IY)*SXG(IX)	GE001420
	IXL=(IX-1)*NY	GE001430
	DO 407 IY=1,NY	GE001440
	I1=IY	GE001450
	I1=IY+IXL	GE001460
	AREDDX(I1)=0.0	GE001470
407	AREDDX(I1)=0.0	GE001480
	RETURN	GE001490
	END	GE001500
		GE001510
		GE001520

SUBROUTINE ADJUST(RG010)	AD000010
COMMON/20/ A/ H(400),V(475),H(500),FM(500),FUE(500),FS(500,15),	AD000020
1 IP(25),T M(500),P(414),RHO(500),LMU(500),	AD000030
1 FXG(25), XU(25),RQUNT(25),RLXG(25),RLXU(25),RSXG(25),RSXU(25),	AD000040
2 STOP (5),SAG(25),SXU(25),X(25),XU(25),	AD000050
3 P(20),E(20),AP(20),ARLAE(20),AS(20),ASNIP(20),AW(20),B(20),	AD000060
4 ISNIP(20),C(20),CSNIP(20),DIFE(20),DIFEE(20),DIFN(20),	AD000070
5 DIFE(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),	AD000080
6 FLOWE(20),FLOWF(20),FLOWH(20),FLOWNE(20),FLOWW(20),R(20),	AD000090
7 FLOWG(20),RQYV(20),RSYG(20),RSYV(20),RV(20),RVCH(20),RVSQ(20),	AD000100
8 SP(20),S(20),SYG(20),SYV(20),Y(20),YV(20),AEDDX(500),	AD000110
9 ADDDY(500),ARLAW(500),VOL(500),	AD000120
X ARSL(25,25),PREFF(25),PRL(25),PRI(25),RSLINE(25,25),	AD000130
1 TEW(25),TLAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),	AD000140
2 KSRIP(25),KSSUM(25),TILL(25)	AD000150
DIMENSION DIFM(20),DIFWN(20),F(11889),FLOWNW(20),FLOWWW(20)	AD000160
EQUIVALENCE(F(1),J(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),	AD000170
1 FLOWFE(1)),(DIFNE(1),DIFHE(1)),(DIFFW(1),DIFEE(1))	AD000180
COMMON/CIMB/	AD000190
1 AK,ARRD, JIG,CCHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,	AD000200
2 EPSI,ERAT,LWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,	AD000210
3 ISTDIM,FUD,FUC,HID,HU,INC,INER,IPLRS,IPREF,IPRINT,ISNIP,	AD000220
4 ISNIP,I,IXMON,IXPREF,IXP1,IXU,IXUP1,IXW,IXIN,IXINY,	AD000230
5 IXINY1,IXINY2,IX2NY2,IYF,IYF1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,	AD000240
6 IYPREF,IYW,IYWH1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,	AD000250
7 JS1,JS,JTEM,JU,JV,KASE,KINFRI,KLT,KRAD,KRHOMU,KSWECP,KTEST,	AD000260
8 LABDII,LSWEEP,NSOLVE,NIDMA,NIMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,	AD000270
9 NXP,NXY,NXYF,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OXB,OXG,PJAY,	AD000280
X IRLP,IPRESS,PLAXP,RF,RESTK,RSCHK,RSMAX,R11,R10,R21,R20,	AD000290
1 STOICH,TOTC,TJHY,TMAX,TMIN,UD,UC,WMIX	AD000300
C-----	AD000310
CHAPTER 1 1 1 1 1 OVERALL-CONTINUITY CORRECTION 1 1 1 1 1 1	AD000320
C-----	AD000330
11 (RG010-2) 1000,2000,3000	AD000340
C	AD000350
C CORRECTION TO U'S ON IXU LINE	AD000360
C-----CALCULATE DELU	AD000370
1000 FLOWST=0.0	AD000380
SRHOA=0.0	AD000390
IF (INC.FO.-1) GO TO 105	AD000400
DO 107 IY=IYF,IYL	AD000410
IF (DSNIP(IY).GT.1.0E08) GO TO 100	AD000420
I=IY+IXINYU	AD000430
SRHOA=SRHOA+FLOWL(IY)/(U(1)+IINY)	AD000440
FLOWST=FLOWST+FLOWE(IY)	AD000450
100 CONTINUE	AD000460
GO TO 107	AD000470
C	AD000480
105 DO 1011 IY=IYF,IYL	AD000490
IF (DSNIP(IY).GT.1.0E08) GO TO 1011	AD000500
I=IY+IXINYU	AD000510
	AD000520

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      SRHOA=SRHOA+FLOWW(IY)/(U(I)+TINY)
      FLOWST=FLOWST+FLOWW(IY)
1011 CONTINUE
107 DELU=(FLOU-PP-FLOWST)/SRHOA
C-----ADD DELU TO U'S ON IXU LINE
      DO 101 IY=IYF,IYL
      IF (DSHIP(IY).GT.1.0E08) GO TO 101
      I=IY+IXINIU
      U(I)=U(I)+DELU
101 CONTINUE
      RETURN
C-----AD000530
AD000540
AD000550
AD000560
AD000570
AD000580
AD000590
AD000600
AD000610
AD000620
AD000630
AD000640
CHAPTER 2 2 2 2 CELL-WISE CONTINUITY CORRECTION 2 2 2 2 AD000650
C-----AD000660
2000 CONTINUE
      IF (KSOLVE(JU).EQ.0) GO TO 200
C-----CORRECT U'S ON TMA LINE
      DO 21 IY=IYF,IYL
      I=IY+IXINIU
      21 U(I)=U(I)+DU(IY)*PP(IY)*FLOAT(INC)
C-----CORRECT V'S ON TMA LINE
200 IF (KSOLVE(JV).EQ.0) GO TO 210
      DO 201 IY=IYF,IYLM1
      IV=IY+IXINIV1
      201 V(IV)=V(IV)+DV(IY)*(PP(IY)-PP(IY+1))
C-----CORRECT P'S ON TMA LINE
210 FLOWST=IX2NY2-1
      SUM=0.0
      AREA=0.0
      DO 22 IY=IYF,IYL
      PP(IY)=PP(IY)*RELAXP
      SUM=SUM+PP(IY)*AREAE(IY)
      22 AREA=AREA+AREAF(IY)
      DELPP=-SUM/AREA
      DO 211 IY=IYF,IYL
      IP=IY+ICONS1
      211 P(IP)=P(IP)+PP(IY)+DELPP
      RETURN
C-----AD000910
CHAPTER 3 3 3 3 OVERALL-MOMENTUM CORRECTION - SNIP 3 3 3 3 AD000920
C-----AD000930
3000 IXL1=IX-1
      SUM=1.0
      AREA=0.0
      ICONS1=IX2NYU-1
      DO 302 IY=IYF,IYL
      IF (DSHIP(IY).GT.1.0E08) GO TO 302
      I=IY+IXINIU
      II=I+1
      IS=I-1
      II=IY+ICONS1
      ILP=IP+IY-2
      AD000940
      AD000950
      AD000960
      AD000970
      AD000980
      AD000990
      AD001000
      AD001010
      AD001020
      AD001030
      AD001040

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AREA=AREA+AREA1(IY)	AD001050
SUM=SUM+DSNIP(IY)*U(I)-ASNIP(IY)*U(IM)-BSNIP(IY)*U(IS)-CSNIP(IY)	AD001060
1 -AREA1(IY)*(P(IP)-P(IEP))	AD001070
302 CONTINUE	AD001080
C	AD001090
DP=-SUM/AREA	AD001100
DP=AREA*1(DP,-5.0)	AD001110
DP=AREA*1(DP,5.0)	AD001120
C	AD001130
IF(IPC,10.1) GO TO 303	AD001140
IF(IXD,1E,IXW) GO TO 304	AD001150
DO 315 IX=2,IXH	AD001160
IXXNY2=(IXX-2)*NYM2-1	AD001170
DO 315 IY=2,MYM1	AD001180
I=IY+IX*NY2	AD001190
315 P(I)=P(I)-DP	AD001200
GO TO 310	AD001210
C	AD001220
304 DO 306 IX=2,IXH	AD001230
IXXNY2=(IXX-2)*NYM2-1	AD001240
DO 306 IY=IYWP1,MYM1	AD001250
I=IY+IX*NY2	AD001260
306 P(I)=P(I)-DP	AD001270
GO TO 310	AD001280
C	AD001290
305 DO 308 IX=IXP1,IXM1	AD001300
IXXNY2=(IXX-2)*NYM2-1	AD001310
DO 308 IY=2,MYM1	AD001320
I=IY+IX*NY2	AD001330
308 P(I)=P(I)+DP	AD001340
C	AD001350
IF(IX,61,IXW) GO TO 310	AD001360
DO 309 IX=2,IXH	AD001370
IXXNY2=(IXX-2)*NYM2-1	AD001380
DO 309 IY=IYWP1,MYM1	AD001390
I=IY+IX*NY2	AD001400
309 P(I)=P(I)+DP	AD001410
310 RETURN	AD001420
END	AD001430

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SUBROUTINE FLOWM(KGOTO)
COMMON/COMA/ U(480),V(475),H(500),FM(500),FUE(500),FS(500,15),
1 FP(20),TFM(500),P(414),RHO(500),EMU(500),
1 PDXG(25),DXU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),
2 STORL(25),SXG(25),SXU(25),X(25),XU(25),
3 A(20),AF(20),AH(20),AREAE(20),AS(20),ASNIP(20),AW(20),B(20),
4 ISNIP(20),C(20),CSNIP(20),DIFE(20),DIFEE(20),DIFN(20),
5 DIFHF(20),DIFH(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),
6 FLOWC(20),FLOWFE(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),
7 PDYG(20),RDYV(20),RSYG(20),RSYV(20),RV(20),RVCR(20),RVSQ(20),
8 SP(20),SH(20),SYG(20),SYV(20),Y(20),YV(20),AEDDX(500),
9 ANDDY(500),AREAN(500),VOL(500),
X ARSL(25,25),PPCFE(25),PRL(25),PRT(25),RSLINE(25,25),
1 IEA(25),FLAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),
2 KSRCE(25),KSSNM(25),T11LL(25)
DIMENSION DIFNW(20),DIFWW(20),F(11889),FLOWNW(20),FLOWWW(20)
EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),
1 FLOWEE(1)),(DIFNW(1),DIFNE(1)),(DIFWW(1),DIFEE(1))
COMMON/COMB/
1 AK,ARRCON,BIG,CHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,
2 LPST,ERAT,EWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,
3 FSTOTM,FUB,FUC,HFU,HV,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,
4 ISWEEP,IX,IXMON,IXPREF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,
5 IX1NY1,IX2NYU,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,
6 IYPREF,IYW,IYWM1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,
7 JS1,JSP,JTEM,JH,JV,KASE,KINPR1,KLT,KRAD,KRHOMU,KSWEET,KTFST,
8 LABPHI,LSWEEP,MSOLVE,NTDMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NYM1,
9 NXM2,NXYG,IXYP,NXYU,NXYV,NY,NYMAX,NYM2,OXB,OXC,PJAY,
X PREEXP,PRESS,RELAXP,RF,RFSTM,RSCHEK,RSMAX,R1I,R1O,R2I,R2O,
1 STOICH,T3,TC,TINY,TMAX,TMIN,UB,UC,WMIX
-----
C IF(KGOTO-2) 1000,2000,3000
C
C      MASS FLOW RATES FOR CONTINUITY CELL FACES
C
C 1000 IF(INC.LQ.-1) GO TO 102
C      EAST FACE OF (IX+1) CELL
C      IF(IX'.LQ.NXM1) GO TO 101
C      IXXNY=IX1NY+NY
C      UC 10 IY=2,NYM1
C      IL=IY+IXXNY
C      IE=IE+IY
C      RHOU=RHO(IE)
C      IF (H(IL).LT.0.0) RHOU=RHO(IE)
C      FLOWE(IY)=RHOU*U(IE)*AREAE(IY)
C      NORTH FACE OF (IX+1) CELL
C      IV=IY+IX1NY1
C      IEV=IV+NY1
C      RHOU=RHO(IE)
C      IF (V(IEV).LT.0.0) RHOU=RHO(IE+1)
C 10 FLOWNE(IY)=RHOU*V(IEV)*AREAN(IE)

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 FL000480
 FL000490
 FL000500
 FL000510
 FL000520

II=IY+I1+IXXNY	FL000530
IV=IY+I1+IXXNY1+NY1	FL000540
RHOV=RHO(I1)	FL000550
IF (V(I1V).LT.0.0) RHOV=RHO(I1+1)	FL000560
FLOWH(IY+I1)=RHOV*V(I1V)*AREAH(I1)	FL000570
GO TO 11	FL000580
C	FL000590
102 IF (I1V.LT.1) GO TO 101	FL000600
IXXNY=IY+I1-NY	FL000610
DO 11 I1=2,NY1	FL000620
I1=IY+IXXNY	FL000630
I1V=I1-NY	FL000640
RHOV=RHO(I1V)	FL000650
IF (V(I1V).LT.0.0) RHOV=RHO(I1V)	FL000660
FLOWH(IY)=RHOV*V(I1V)*AREAH(IY)	FL000670
IV=IY+IXXNY1	FL000680
I1V=IV-NY1	FL000690
RHOV=RHO(I1V)	FL000700
IF (V(I1V).LT.0.0) RHOV=RHO(I1V+1)	FL000710
11 FLOWH(IY)=RHOV*V(I1V)*AREAH(IY)	FL000720
I1=IY+I1+IXXNY	FL000730
I1V=IY+I1+IXXNY1-NY1	FL000740
RHOV=RHO(I1V)	FL000750
IF (V(I1V).LT.0.0) RHOV=RHO(I1V+1)	FL000760
FLOWH(IY+I1)=RHOV*V(I1V)*AREAH(IY)	FL000770
C NORTH FACE OF IX CELL	FL000780
101 I=IY+I1+IXXNY	FL000790
IV=IY+I1+IXXNY1	FL000800
RHOV=RHO(I)	FL000810
IF (V(I1V).LT.0.0) RHOV=RHO(I+1)	FL000820
FLOWH(IY+I1)=RHOV*V(I1V)*AREAH(I)	FL000830
DO 12 I1=2,NY1	FL000840
I1=IY+IXXNY1	FL000850
I1=IY+IXXNY	FL000860
RHOV=RHO(I1)	FL000870
IF (V(I1V).LT.0.0) RHOV=RHO(I1+1)	FL000880
12 FLOWH(IY)=RHOV*V(I1V)*AREAH(I)	FL000890
RETURN	FL000900
C	FL000910
2000 CONTINUE	FL000920
C	FL000930
IF (I1V.LT.-1) GO TO 21	FL000940
C EAST FACE OF IX CELL	FL000950
DO 20 I1=2,NY1	FL000960
I1=IY+IXXNY	FL000970
I1=I1+NY	FL000980
RHOV=RHO(I1)	FL000990
IF (V(I1V).LT.0.0) RHOV=RHO(I1)	FL001000
20 FLOWH(IY)=RHOV*V(I1V)*AREAH(IY)	FL001010
RETURN	FL001020
C	FL001030
21 DO 22 I1=2,NY1	FL001040

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I=IY+IX*HY
IW=I-HY
RHOU=RHO(IW)
IF (U(IW).LT.0.0) RHOU=RHO(I)
22 FLOWE(IY)=RHOU*U(IW)*AREAE(IY)
RETURN
3000 IF (KOUNT(IX).GT.1) RETURN
DO 30 IY=2,NYM1
I=IY+IX*HY
IL=I+HY
IW=I-HY
RHOU=RHO(I)
IF (U(I).LT.0.0) RHOU=RHO(IE)
FLOWE(IY)=RHOU*U(I)*AREAE(IY)
RHOU=RHO(IW)
IF (U(IW).LT.0.0) RHOU=RHO(I)
30 FLOWW(IY)=RHOU*U(IW)*AREAE(IY)
RETURN
END

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FL001050
FL001060
FL001070
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FL001090
FL001100
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FL001120
FL001130
FL001140
FL001150
FL001160
FL001170
FL001180
FL001190
FL001200
FL001210
FL001220
FL001230

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SUBROUTINE COEFF (LPHI)															CF000010	
C	-----															CF000020
C	CHAPTER 0	0	0	0	0	0	DECLARATIONS	0	0	0	0	0	0	0	0	CF000030
C	COMMON/COIA/ U(420),V(475),H(500),FM(500),FUE(500),FS(500,15),															CF000050
	1 PP(20),TEN(500),P(414),RHO(500),EMU(500),															CF000060
	1 DXG(25),DXU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),															CF000070
	2 STORC(25),SXG(25),SXU(25),X(25),XU(25),															CF000080
	3 A(20),AE(20),AN(20),AREAE(20),AS(20),ASNIP(20),AW(20),B(20),															CF000090
	4 GSNIP(20),C(20),CSNIP(20),DIFE(20),DIFEE(20),DIFN(20),															CF000100
	5 DIFNE(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),															CF000110
	6 FLOWE(20),FLOWEE(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),															CF000120
	7 RDXG(20),RDXV(20),RSYG(20),RSYV(20),RV(20),RVCB(20),RVSQ(20),															CF000130
	8 SP(20),SU(20),SYG(20),SYV(20),Y(20),YV(20),AEDOX(500),															CF000140
	9 ANDDY(500),AREAH(500),VOL(500),															CF000150
	X ARSL(25,25),PREFF(25),PRL(25),PRT(25),RSLINE(25,25),															CF000160
	1 IEW(25),ILAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),															CF000170
	2 RSREF(25),RSSUM(25),TITLE(25)															CF000180
	DIMENSION DIFNW(20),DIFFW(20),F(11889),FLOWNW(20),FLOWWW(20)															CF000190
	EQUIVALENCE(I(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),															CF000200
	1 FLOWEE(1)),(DIFNW(1),DIFNE(1)),(DIFFW(1),DIFEE(1))															CF000210
	COMMON/COMB/															CF000220
	1 AK,ARRCON,BIG,CHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,															CF000230
	2 EPST,ENRAT,CWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,															CF000240
	3 FSTOIM,FUB,FUC,HFU,HW,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,															CF000250
	4 ISWEEP,IX,IXMON,IXPREF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,															CF000260
	5 IX1NY1,IX2NYU,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,															CF000270
	6 IYPREF,IYW,IYWM1,IYWPI,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,															CF000280
	7 JS1,JS2,JTEM,JU,JV,KASE,KINPRI,KLT,KRAD,KRHOMU,KSWEET,KTEST,															CF000290
	8 LARPHI,LSWEEP,LSOLVE,NTOMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,															CF000300
	9 NXM2,NXYG,NXYP,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OXB,OXC,PJAY,															CF000310
	X PREXP,PRESS,RELAXP,RF,RFSTH,RSCHK,RSMAX,R11,R10,R21,R20,															CF000320
	1 STOICH,TR,TC,TINY,TMAX,TMIN,UB,UC,WMIX															CF000330
	DIMENSION U(20)															CF000340
C	-----															CF000350
C	CHAPTER 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	CF000360
C	PRELIMINARIES															CF000370
C	-----															CF000380
C	DEFINE ARITHMETIC FUNCTION FOR COMBINING															CF000390
C	APPROPRIATELY CONVECTION AND DIFFUSION CONTRIBUTIONS															CF000400
C	CONDIF(DIFF,CONV)=AMAX1(DIFF, DIFF+CONV)															CF000410
C	JPHI=LPHI															CF000420
	IF(JPHI.EQ.0) GO TO 10															CF000430
	IF(JPHI.EQ.JU) GO TO 20															CF000440
	IF(JPHI.EQ.JV) GO TO 30															CF000450
	IF(JPHI.EQ.JPP) GO TO 40															CF000460
	GO TO 50															CF000470
C																CF000480
C																CF000490
C	DIFFUSION TERMS FOR CONTINUITY CELLS															CF000500
C																CF000510
C																CF000520

10	DO 150 IY=2,NYM1	CF000530
	I=IY+IX1NY	CF000540
	IW=I-NY	CF000550
	IE=I+NY	CF000560
	IWW=IW-NY	CF000570
	IEL=IE+NY	CF000580
	DIFN(IY)=0.5*(EMU(I+1)+EMU(I))*ANDDY(I)	CF000590
	IF (IX.EQ.2) GO TO 153	CF000600
	DIFW(IY)=0.5*(EMU(IW)+EMU(I))*AEDDX(IW)	CF000610
	II (INC.EQ.1) GO TO 154	CF000620
	DIFWW(IY)=0.5*(EMU(IWW)+EMU(IW))*AEDDX(IWW)	CF000630
	DIFNW(IY)=0.5*(EMU(IW+1)+EMU(IW))*ANDDY(IW)	CF000640
	GO TO 154	CF000650
153	DIFW(IY)=0.0	CF000660
154	IF (IX.EQ.NXM1) GO TO 156	CF000670
	DIFE(IY)=0.5*(EMU(I)+EMU(IE))*AEDDX(I)	CF000680
	IF (INC.EQ.-1) GO TO 158	CF000690
	DIFEL(IY)=0.5*(EMU(IE)+EMU(IEE))*AEDDX(IE)	CF000700
	DIFNE(IY)=0.5*(EMU(IE+1)+EMU(IE))*ANDDY(IE)	CF000710
	GO TO 158	CF000720
156	DIFE(IY)=0.0	CF000730
158	CONTINUE	CF000740
	DIFN(IYL)=0.0	CF000750
	DIFNE(IYL)=0.0	CF000760
	DIFN(NYM1)=0.0	CF000770
	DIFNE(NYM1)=0.0	CF000780
	RETURN	CF000790
C-----		CF000800
CHAPTER 2 2 2 2 2 2 2 COEFFICIENTS FOR U-EQUATION 2 2 2 2 2 2 2		2CF000810
C-----		CF000820
20	IF (INC.EQ.-1) GO TO 289	CF000830
	CN=FLOWN(IYFM1)+FLOWNE(IYFM1)	CF000840
	IF (IXU.EQ.2) CN=CN+FLOWN(IYFM1)	CF000850
	IF (IXU.EQ.NXM2) CN=CN+FLOWNE(IYFM1)	CF000860
	AN(IYFM1)=0.5*AMAX1(0.0,-CN)	CF000870
C		CF000880
	DO 26 IY=IYF,IYL	CF000890
	DN=DIFNE(IY)+DIFN(IY)	CF000900
	DE=DIFEE(IY)+DIFE(IY)	CF000910
	DW=DIFW(IY)+DIFE(IY)	CF000920
	CS=CN	CF000930
	CN=FLOWNE(IY)+FLOWN(IY)	CF000940
	CE=FLOWEE(IY)+FLOWE(IY)	CF000950
	CW=FLOWW(IY)+FLOWE(IY)	CF000960
	IF (IXU.NE.NXM2) GO TO 287	CF000970
	CN=CN+FLOWNE(IY)	CF000980
	DN=DN+DIFNE(IY)	CF000990
	CE=FLOWEE(IY)+FLOWE(IY)	CF001000
	DE=0.0	CF001010
	GO TO 286	CF001020
287	IF (IXU.NE.2) GO TO 286	CF001030
	DW=0.0	CF001040

	CW=FLOWW(IY)+FLOWW(IY)	CF001050
	CN=CN+FLOWN(IY)	CF001060
	DN=DN+DIFN(IY)	CF001070
C-----	COMBINING DIFFUSION AND CONVECTION CONTRIBUTIONS	CF001080
286	AS(IY)=AN(IY-1)+0.5*CS	CF001090
	AN(IY)=0.5*CONDIF(DN,-CN)	CF001100
	AL(IY)=0.5*CONDIF(DL,-CL)	CF001110
26	AW(IY)=0.5*CONDIF(DW,-CW)	CF001120
	GO TO 299	CF001130
C		CF001140
289	CN=FLOWW(IYFM1)+FLOWN(IYFM1)	CF001150
	IF (IXU.EQ.2) CN=CN+FLOWW(IYFM1)	CF001160
	IF (IXU.EQ.NXM2) CN=CN+FLOWN(IYFM1)	CF001170
	AN(IYFM1)=0.5*AMAX1(0.0,-CN)	CF001180
C		CF001190
	DO 27 IY=IYF,IYL	CF001200
	DN=DIFW(IY)+DIFN(IY)	CF001210
	DL=DIFC(IY)+DIFW(IY)	CF001220
	DW=DIFW(IY)+DIFW(IY)	CF001230
	CS=CN	CF001240
	CN=FLOWW(IY)+FLOWN(IY)	CF001250
	CL=FLOWC(IY)+FLOWW(IY)	CF001260
	CW=FLOWW(IY)+FLOWW(IY)	CF001270
	IF (IXU.NE.NXM2) GO TO 297	CF001280
	CN=CN+FLOWN(IY)	CF001290
	DN=DN+DIFN(IY)	CF001300
	CL=FLOWC(IY)+FLOWC(IY)	CF001310
	DL=0.0	CF001320
	GO TO 296	CF001330
297	IF (IXU.NE.2) GO TO 296	CF001340
	DW=0.0	CF001350
	CW=FLOWW(IY)+FLOWW(IY)	CF001360
	CN=CN+FLOWW(IY)	CF001370
	DN=DN+DIFN(IY)	CF001380
296	AS(IY)=AN(IY-1)+0.5*CS	CF001390
	AN(IY)=0.5*CONDIF(DN,-CN)	CF001400
	AL(IY)=0.5*CONDIF(DL,-CL)	CF001410
27	AW(IY)=0.5*CONDIF(DW,-CW)	CF001420
C		CF001430
299	CALL SOURCE(JU)	CF001440
C		CF001450
C	IYL BOUNDARY	CF001460
C		CF001470
	IF (IYL.NE.IYM1) GO TO 1070	CF001480
	CALL WALL(NY,STERM,STERM1,0,JP(I))	CF001490
	SP(IYL)=SP(IYL)-STERM1	CF001500
1070	IF (KTEST.GT.2) CALL TEST(31)	CF001510
C		CF001520
	IYI=IYI+IYL	CF001530
	IS=IYFM1+IXI*NYI	CF001540
	A(IYFM1)=0.0	CF001550
	R(IYFM1)=0(IS)	CF001560

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DO 290 IY=IYF,IYL	CF001570
IYM1=IY-1	CF001580
I=IY+IX1NYU	CF001590
IP=IYM1+IX2NYU	CF001600
IEP=IP+NYM2	CF001610
IE=I+NY	CF001620
IW=I-NY	CF001630
C(IY)=SU(IY)+AE(IY)*U(IE)+AW(IY)*U(IW)	CF001640
D(IY)=AE(IY)+AW(IY)+AS(IY)+AN(IY)-SP(IY)	CF001650
CSNIP(IY)=C(IY)-AREAE(IY)*(P(IP)-P(IEP))	CF001660
DSNIP(IY)=D(IY)	CF001670
ASNIP(IY)=AN(IY)	CF001680
BSNIP(IY)=AS(IY)	CF001690
DU(IY)=AREAE(IY)/D(IY)	CF001700
TERM=D(IY)-AS(IY)*A(IYM1)	CF001710
A(IY)=AN(IY)/TERM	CF001720
290 B(IY)=(C(IY)+B(IYM1)*AS(IY))/TERM	CF001730
IF (ISNIP.EQ.0) RETURN	CF001740
SUM=0.0	CF001750
DO 291 IY=IYF,IYL	CF001760
IF (SP(IY).LT.-1.0E08) GO TO 291	CF001770
I=IY+IX1NYU	CF001780
RS=D(IY)*U(I)-C(IY)-AN(IY)*U(I+1)-AS(IY)*U(I-1)	CF001790
SUM=SUM+RS	CF001800
291 CONTINUE	CF001810
RSLINE(IXU,JPHI)=SUM/RSREF(JPHI)	CF001820
ARSL(IXU,JPHI)=ABS(RSLINE(IXU,JPHI))	CF001830
DO 292 IDASH=IYF,IYL	CF001840
IY=IYFL-IDASH	CF001850
I=IY+IX1NYU	CF001860
292 U(I)=A(IY)*U(I+1)+B(IY)	CF001870
RETURN	CF001880
C-----	CF001890
CHAPTER 3 3 3 3 3 3 COEFFICIENTS FOR V-EQUATION 3 3 3 3 3 3	CF001900
C-----	CF001910
30 CN=FLOWN(IYFM1)	CF001920
AN(IYFM1)=AMAX1(0.0,-CN)	CF001930
CN=CN+CM	CF001940
DO 36 IY=IYF,IYLM1	CF001950
IYP1=IY+1	CF001960
DN=DIFN(IY)+DIFN(IYP1)	CF001970
DE=DIFE(IY)+DIFE(IYP1)	CF001980
DW=DIFW(IY)+DIFW(IYP1)	CF001990
CS=CM	CF002000
CH=FLOWH(IY)+FLOWH(IYP1)	CF002010
CE=FLOWL(IY)+FLOWL(IYP1)	CF002020
CW=FLOWW(IY)+FLOWW(IYP1)	CF002030
IF (IY.NE.NYM2) GO TO 387	CF002040
CE=CE+FLOWC(IYP1)	CF002050
CW=CW+FLOWW(IYP1)	CF002060
DE=DE+DIFE(IYP1)	CF002070
DW=DW+DIFW(IYP1)	CF002080

CN=FLOWN(IYP1)+FLOWN(IYP1)	CF002090
DH=0.0	CF002100
GO TO 386	CF002110
387 IF (IY.NE.2) GO TO 386	CF002120
CE=CE+FLOWL(IY)	CF002130
CW=CW+FLOWW(IY)	CF002140
DE=DE+DIFE(IY)	CF002150
DW=DW+DIFW(IY)	CF002160
C----- COMBINING DIFFUSION AND CONVECTION CONTRIBUTIONS	CF002170
386 AS(IY)=AN(IY-1)+CS*0.5	CF002180
AH(IY)=0.5*CONDIF(DW,-CN)	CF002190
AE(IY)=0.5*CONDIF(DE,-CE)	CF002200
36 AW(IY)=0.5*CONDIF(DW, CW)	CF002210
CALL SOURCE(JV)	CF002220
C	CF002230
C IXL BOUNDARY	CF002240
C	CF002250
IF (IX.NE.IXLM1) GO TO 2054	CF002260
DO 2050 IY=IYF,IYLM1	CF002270
CALL WALL(NX,STERM,STERM1,IY,JPH1)	CF002280
2050 SP(IY)=SP(IY)-STERM1	CF002290
2054 IF (KTEST.GT.2) CALL TEST(31)	CF002300
IYFL=IYF+IYLM1	CF002310
IS=IYFM1+IX1NY1	CF002320
A(IYFM1)=0.0	CF002330
B(IYFM1)=V(IS)	CF002340
DV(IYFM1)=0.0	CF002350
DO 390 IY=IYF,IYLM1	CF002360
IYM1=IY-1	CF002370
I=IY+IX1NY1	CF002380
IL=I+NYM1	CF002390
IW=I-NYM1	CF002400
IA=IY+IX1NY	CF002410
C(IY)=SU(IY)+AE(IY)*V(IL)+AW(IY)*V(IW)	CF002420
D(IY)=AE(IY)+AW(IY)+AS(IY)+AN(IY)-SP(IY)	CF002430
DV(IY)=AREAN(IA)/D(IY)	CF002440
TERM=D(IY)-AS(IY)*A(IYM1)	CF002450
A(IY)=AN(IY)/TERM	CF002460
390 B(IY)=(C(IY)+B(IYM1)*AS(IY))/TERM	CF002470
SUM=0.0	CF002480
DO 391 IY=IYF,IYLM1	CF002490
IF (SP(IY) .LT. -1.0E08) GO TO 391	CF002500
I=IY+IX1NY1	CF002510
RS=D(IY)*V(I)-C(IY)-AN(IY)*V(I+1)-AS(IY)*V(I-1)	CF002520
SUM=SUM+RS	CF002530
391 CONTINUE	CF002540
RSLINE(IX,JPH1)=SUM/RSREF(JPH1)	CF002550
ARSL(IX,JPH1)=ABS(RSLINE(IX,JPH1))	CF002560
DO 392 IDASH=IYF,IYLM1	CF002570
IY=IYFL-IDASH	CF002580
I=IY+IX1NY1	CF002590
392 V(I)=A(IY)*V(I+1)+B(IY)	CF002600

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RETURN	CF002610
C	CF002620
CHAPTER 4 4 4 4 4 COEFFICIENTS FOR PRESSURE-CORRECTION EQUATION 4 4	CF002630
C	CF002640
40 DO 46 IY=IYF,IYL	CF002650
I=IXINY+IY	CF002660
II=I+1	CF002670
IL=I+NY	CF002680
IS=I-1	CF002690
IW=I-NY	CF002700
IYM1=IY-1	CF002710
C	CF002720
RHOCEL=RHO(IN)	CF002730
IF (FLOWN(IY).GE.0.0) RHOCEL=RHO(I)	CF002740
AN(IY)=RHOCEL*AREAN(I)*DV(IY)	CF002750
C	CF002760
RHOCEL=RHO(I)	CF002770
IF (FLOWN(IYM1).GE.0.0) RHOCEL=RHO(IS)	CF002780
AS(IY)=RHOCEL*AREAN(IS)*DV(IYM1)	CF002790
C	CF002800
IF (INC.EQ.-1) GO TO 41	CF002810
C	CF002820
AW(IY)=0.0	CF002830
RHOCEL=RHO(IE)	CF002840
IF (FLOWE(IY).GE.0.0) RHOCEL=RHO(I)	CF002850
AE(IY)=RHOCEL*AREAE(IY)*DU(IY)	CF002860
C	CF002870
GO TO 46	CF002880
C	CF002890
41 AE(IY)=0.0	CF002900
RHOCEL=RHO(I)	CF002910
IF (FLOWW(IY).GE.0.0) RHOCEL=RHO(IW)	CF002920
AW(IY)=RHOCEL*AREAE(IY)*DU(IY)	CF002930
C	CF002940
46 CONTINUE	CF002950
C	CF002960
CALL SOURCE(JPP)	CF002970
C	CF002980
IF (KTEST.GT.2) CALL TEST(31)	CF002990
IYFL=IYF+IYL	CF003000
A(IYM1)=0.0	CF003010
B(IYM1)=0.0	CF003020
PP(IYLP1)=0.0	CF003030
DO 490 IY=IYF,IYL	CF003040
IYM1=IY-1	CF003050
C(IY)=SU(IY)	CF003060
D(IY)=AE(IY)+AW(IY)+AS(IY)+AN(IY)-SP(IY)	CF003070
TERM=D(IY)-AS(IY)*A(IYM1)	CF003080
A(IY)=AN(IY)/TERM	CF003090
490 B(IY)=(C(IY)+B(IYM1)*AS(IY))/TERM	CF003100
DO 492 IDASH=IYF,IYL	CF003110
IY=IYFL-IDASH	CF003120

492	PP(IY)=A(IY)*PP(IY+1)+B(IY)	CF003130
	RETURN	CF003140
C	-----	CF003150
CHAPTER	5 5 5 5 PHI EQUATION 5 5 5 5 5 5 5	CF003160
C	-----	CF003170
50	RPREF=1./RPREFF(JPHI)	CF003180
	AM(IYFM1)=AMAX1(0.0,-FLOWN(IYFM1))	CF003190
	DO 56 IY=IYF,IYL	CF003200
C	----- COMBINING DIFFUSION AND CONVECTION CONTRIBUTIONS	CF003210
	AS(IY)=AN(IY-1)+FLOWN(IY-1)	CF003220
	AM(IY)=CONDIF(DIFN(IY)*RPREF,-FLOWN(IY))	CF003230
	AE(IY)=CONDIF(DIFE(IY)*RPREF,-FLOWE(IY))	CF003240
56	AW(IY)=CONDIF(DIFW(IY)*RPREF, FLOWW(IY))	CF003250
C		CF003260
	CALL SOURCE(JPHI)	CF003270
C		CF003280
	IF (RTEST.GT.2) CALL TEST(31)	CF003290
C		CF003300
	IYFL=IYF+IYL	CF003310
	ICONST=IX(IY(JPHI))+IZERO(JPHI)	CF003320
	IS=IYFM1+ICONST	CF003330
	A(IYFM1)=0.0	CF003340
	B(IYFM1)=F(IS)	CF003350
	DO 590 IY=IYF,IYL	CF003360
	IYM1=IY-1	CF003370
	I=IY+ICONST	CF003380
	IE=I+NY	CF003390
	IW=I-NY	CF003400
	C(IY)=SU(IY)+AE(IY)*F(IE)+AW(IY)*F(IW)	CF003410
	D(IY)=AC(IY)+AW(IY)+AS(IY)+AN(IY)-SP(IY)	CF003420
	TERM=D(IY)-AS(IY)*A(IYM1)	CF003430
	A(IY)=AM(IY)/TERM	CF003440
590	B(IY)=(C(IY)+B(IYM1)*AS(IY))/TERM	CF003450
	SUM=0.0	CF003460
	DO 591 IY=IYF,IYL	CF003470
	IF (SP(IY).LT.-1.0E08) GO TO 591	CF003480
	I=IY+ICONST	CF003490
	RS=D(IY)*F(I)-C(IY)-AN(IY)*F(I+1)-AS(IY)*F(I-1)	CF003500
	SUM=SUM+RS	CF003510
591	CONTINUE	CF003520
	RSLINE(IX,JPHI)=SUM/RSREF(JPHI)	CF003530
	ARSL(IX,JPHI)=ABS(RSLINE(IX,JPHI))	CF003540
	DO 592 IDASH=IYF,IYL	CF003550
	IY=IYFL-IDASH	CF003560
	I=IY+ICONST	CF003570
592	F(I)=A(IY)*F(I+1)+B(IY)	CF003580
	RETURN	CF003590
	END	CF003600

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SUBROUTINE TLST(KGOTO)
COMMON/COMB/ D(480),V(475),H(500),FM(500),FUE(500),FS(500,15),
1 FP(20),TLM(500),P(414),RHO(500),EMU(500),
1 LXG(25),XU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),
2 STORE(25),SXG(25),SXU(25),X(25),XU(25),
3 A(20),E(20),AB(20),AKLAE(20),AS(20),ASNIP(20),AW(20),B(20),
4 LSHIP(20),C(20),CSHIP(20),DIFE(20),DIFEC(20),DIFW(20),
5 DIFFE(20),DIFW(20),DSHIP(20),DU(20),DV(20),DYV(20),
6 FLOWE(20),FLOWEC(20),FLOWN(20),FLOWNF(20),FLOWW(20),R(20),
7 RDXG(25),RDXV(20),RSYG(20),PSYV(20),RV(20),RVCB(20),RVSQ(20),
8 SP(20),SU(20),SYG(20),SYV(20),Y(20),YV(20),AEDDX(500),
9 ANDLY(400),AREAN(500),VOL(500),
Y ARSL(25,25),PPFFC(25),PRL(25),PRT(25),RSLINE(25,25),
1 LEW(25),LAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),
2 RSP(25),RSSUM(25),TITLE(25)
DIMENSION DIFNW(20),DIFFW(20),F(11889),FLOWNW(20),FLOWWW(20)
EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),
1 FLOWEE(1)),(DIFNW(1),DIFNE(1)),(DIFFW(1),DIFFE(1))
COMMON/COMB/
1 AK,ARR,OM,BIG,CHECK,CMIX,DATA(6),OP,FL1,EL2,EMA,EMF,EMUREF,
2 FPSY,E,KAT,CWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,
3 FSTOIM,FUB,FUC,HFU,HW,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,
4 ISWLP,IX,IXMON,IXPREF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,
5 IX1NY1,IX2NYU,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,
6 IYPRFF,IYW,IYWM1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,
7 JS1,JS2,JTEM,JH,JV,KASL,KINPRI,KLT,KRAD,KRHOMU,KSWECP,KTFST,
8 LAIPHI,LSWEEP,NSOLVE,NTOMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,
9 NXM2,NYG,NXYP,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OBJ,OCX,PJAY,
X PREXP,PRESS,REFLXP,RF,RFSTP,RSCHK,RSMAX,R11,R10,R21,R20,
1 STOICH,TE,TC,TINY,TMAX,TMIN,UB,UC,WMIX
-----
CHAPTER 1 1 1 1 PRINT-OUTS FOR LEVEL 1 ONWARDS 1 1 1
C
C----- GEOMETRICAL QUANTITIES RELATED TO GRID
C IF (KGOTO,HL,11) GO TO 3000
C
WRITE(6,200) KTFST
200 FORMAT(/1,26HDIAGNOSING PRINT-OUT LEVEL,14,2X,30(1H-))
WRITE(6,201) (K,X(K),DXG(K),SXG(K),K=1,NX)
201 FORMAT(/1X,2HIX,1X,10H X,10H DXG,10H SXG/
1(1X,12,1X,1P3E10.2))
WRITE(6,202) (K,XU(K),DXU(K),SXU(K),K=1,NX)
202 FORMAT(/1X,2HIX,1X,10H XU,10H DXU,10H SXU
1/(1X,12,1X,1P3E10.2))
WRITE(6,203) (K,Y(K),R(K),DYG(K),SYG(K),AREAE(K),K=1,NY)
203 FORMAT(/1X,2HIY,1X,10H Y,10H R,10H DYG,
1 10H SYG,10H AREAE/(1X,12,1X,1P5E10.2))
WRITE(6,204) (K,YV(K),RV(K),RVCB(K),DYV(K),SYV(K),K=1,NY)
204 FORMAT(/1X,2HIY,1X,10H YV,10H RV,10H RVCB,
1 10H DYV,10H SYV/
2(1X,12,1X,1P5E10.2))

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K1=1	TE000530
K2=MIN(10,10)	TE000540
208 WRITE (6,905) (K,K=K1,K2)	TE000550
205 FORMAT(1X,5HAP(AH/4X,5HIX=.10110/1X,2H1Y)	TE000560
DO 205 1Y=1,NY	TE000570
K3=1Y+(1-1)*NY	TE000580
K4=1Y+(1-2)*NY	TE000590
206 WRITE (6,207) 1Y,(AREAJ(K),K=K3,K4,NY)	TE000600
207 FORMAT(1X,12,4X,1P10E10.2)	TE000610
IF (K2.EQ.1X) RETURN	TE000620
K1=K2+1	TE000630
K2=MIN(10,K2+10,1X)	TE000640
GO TO 208	TE000650
RETURN	TE000660
C----- VARIABLE INFORMATION	
3000 IF (K010.NE.12) GO TO 8000	TE000670
C	TE000680
WRITE (6,300)	TE000690
300 FORMAT(//1X,30HDEPENDENT VARIABLE INFORMATION,20(1H-)/)	TE000700
WRITE (6,301) NSOLVE,(TITLE(K),K=1,NSOLVE)	TE000710
301 FORMAT(1X,30HNSOLVE=.1H,1X,5(1H-),10(A4,1H,1X))	TE000720
IF (KSOLVE(JMP).EQ.0) GO TO 30	TE000730
WRITE (6,302)	TE000740
302 FORMAT(1X,14X,44HPRESSURE CORRECTION EQUATION IS ALSO SOLVED.)	TE000750
30 WRITE (6,303)	TE000760
303 FORMAT(1X,4H J ,4HJPHI,3H KSOLVE,	TE000770
1 PH , 12E0.8H ILAST,6H IEW)	TE000780
WRITE (6,304) (K,TITLE(K),KSOLVE(K),	TE000790
1 12E0(K),ILAST(K),IEW(K),K=1,JLAST)	TE000800
304 FORMAT (1X,12,2X,A4,41B)	TE000810
RETURN	TE000820
C-----	TE000830
CHAPTER 2 2 2 2 2 PRINT-OUTS FOR LEVEL 2 ONWARDS 2 2 2	TE000840
C	TE000850
C-----STAPLED ALLOCITIES AND THEIR RESIDUAL SOURCES ON TDMA LINE	TE000860
8000 IF (K010.NE.21) GO TO 10000	TE000870
C	TE000880
IF (K1EST.EQ.2) GO TO 804	TE000890
IF (LABPHI.EQ.1) WRITE (6,803) 1X,KOUNT(1X)	TE000900
IF (LABPHI.EQ.2.AND.(IXU.EQ.NXP1.OR.IXU.EQ.1)) WRITE (6, 803)	TE000910
1 1X,KOUNT(1X)	TE000920
903 FORMAT(1X,53(1H-),4H 1X=.12,12H, KOUNT(1X)=,13)	TE000930
804 SYMBOL=1H	TE000940
IF (LABPHI.GT.10) SYMBOL=1H	TE000950
ICONST=1X*(LABPHI)+12E0(LABPHI)	TE000960
K1=IYFM)+ICONST	TE000970
K2=IYLP1+ICONST	TE000980
IF (LABPHI.EQ.10) K2=IYL+ICONST	TE000990
IF (LABPHI.EQ.10) GO TO 805	TE001000
WRITE (6,870) 1X,SYMBOL,TITLE(LABPHI),(1(K),K=K1,K2)	TE001010
IF (LABPHI.GT.10) GO TO 806	TE001020
800 FORMAT(1X,3HIX=.12,1H,1X,A1,11H VALUES OF .A4,1H,1P5E10.2,	TE001030
	TE001040

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1 5(/IX,4X,1P5E10.2)
WRITE (6,801) TITLE(LABPHI),IX,RSLINE(IX,LABPHI)
GO TO 336
805 WRITE (6,840) IX,SYMBOL,TITLE(LABPHI),(F(K),K=K1,K2)
WRITE (6,841) TITLE(LABPHI),IX,RSLINE(IX,LABPHI)
806 CONTINUE
801 FORMAT(1X,30ALGEBRAIC SUM OF RESIDUAL SOURCES OF ,A4.7H AT IX=,
1 12,4H IX,10X,1P5E10.2)
RETURN
C----- LAN-PRESSURE-CORRECTION QUANTITIES
1000 IF (K6010.NE.22) GO TO 11000
C
WRITE (6,1091) IX,FLOWUP,FLOWST
1090 FORMAT(/1X,5HIX=,12,5H.....7HFLOWUP,,7HFLOWST,,
1P5E10.2)
K1=IYFM1+IXINYH
K2=IYLP1+IXINYH
WRITE (6,1091) (H(K),K=K1,K2)
1091 FORMAT(1X,29HADJUST(1) U(IYFM1-IYLP1),1P5E10.2,
1 5(/IX,4X,1P5E10.2))
RETURN
C----- P-CORRECTION QUANTITIES
11000 IF (K6010.NE.23) GO TO 12000
C
WRITE (6,1093) IX,RSLINE(IX,PP)
1093 FORMAT(/1X,42HALGEBRAIC SUM OF ERROR MASS SOURCES AT IX=,13,
1 5H 1X,14X,1P5E10.2)
WRITE (6,1090) IX,(PP(K),K=IYF,IYL)
1090 FORMAT(/1X,3HIX=,12,2X,15HPP(IYF TO IYL) ,5X,1P5E10.2,
1 5(/IX,4X,1P5E10.2))
K1=IYFM1+IXIY(JU)
K2=IYLP1+IXIY(JU)
WRITE (6,1091) IX,(U(K),K=K1,K2)
1091 FORMAT(1X,30IX=,12,2X,24HPP C. U(IYFM1 TO IYLP1) ,1P5E10.2,
1 5(/IX,4X,1P5E10.2))
K1=IYFM1+IXIY(JV)
K2=IYLP1+IXIY(JV)
WRITE (6,1092) IX,(V(K),K=K1,K2)
1092 FORMAT(1X,30IX=,12,2X,18HPP C. V(IYFM1-IYL),1P5E10.2,
1 5(/IX,4X,1P5E10.2))
RETURN
C
12000 IF (K6010.NE.24) GO TO 2000
WRITE (6,1200) DP
1200 FORMAT(/1X,29HADJUST(3), 4LAN=P CORRECTION=,1P5E10.2)
K1=2
K2=0140(H:M1,11)
1200 WRITE (6,1205) (K,K=K1,K2)
1205 FORMAT(/1X,25HPPRESSURES AFTER ADJUST(3)/4X,5HIX=,10110/
1 1X,2HIY)
DO 1206 1,04SH=1,04P2
1206 IF=IYFASH

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	K3=1+(1-2)*NYM2-1	TE001570
	K4=1+(1-2)*NYM2-1	TE001580
1206	WRITE(6,217) IX,(P(K),K=K3,K4,NYM2)	TE001590
	IF (K2.EQ.1) RETURN	TE001600
	K1=K2+1	TE001610
	K2=MIN0(K2+10,IXM1)	TE001620
	GO TO 1206	TE001630
	RETURN	TE001640
C-----		TE001650
CHAPTER 3	3 3 3 PRINT-OUTS FOR LEVEL 3 ONWARDS 3 3 3 3	TE001660
C		TE001670
C-----	COEFFICIENTS OF FINITE-DIFFERENCE EQUATIONS	TE001680
2070	IF (K0010.NE.31) GO TO 4000	TE001690
C		TE001700
	IF (LABPHI.EQ.0) GO TO 2022	TE001710
	WRITE(6,2120) TITLE(LABPHI),IX	TE001720
	GO TO 2025	TE001730
2022	WRITE(6,2120) TITLE(LABPHI),IX	TE001740
2023	CONTINUE	TE001750
2020	FORMAT(//IX,16HCOEFFICIENTS OF ,A4,2X,17HEQUATION FOR IX=,14,2X,2	TE001760
	10(10=)//1X,20HY,2X,10H AN,10H AS,10H AE,	TE001770
	110H AW,10H SU,10H SP)	TE001780
	K2=IYL	TE001790
	IF (LABPHI.EQ.2) K2=IYLM1	TE001800
	WRITE(6,2021)(K,AN(K),AS(K),AE(K),AW(K),SU(K),SP(K),K=IY,K2)	TE001810
2021	FORMAT(1X,12,2X,1P6E10.2)	TE001820
	RETURN	TE001830
C		TE001840
C	MASS FLOW RATES	TE001850
C		TE001860
4000	IF (K0010.NE.40) GO TO 4100	TE001870
	IF (INC.CO.-1) GO TO 401	TE001880
	WRITE(6,400)	TE001890
	WRITE(6,409) (K,FLOWN(K),FLOWE(K),FLOWW(K),FLOWEE(K),FLOWNE(K),	TE001900
	1K=2,1Y)	TE001910
400	FORMAT(//1X,20HY,2X,10H FLOWN,10H FLOWE,10H FLOWW,	TE001920
	110H FLOWEE,10H FLOWNE/)	TE001930
409	FORMAT(1X,12,2X,1P5E10.2)	TE001940
	GO TO 412	TE001950
401	WRITE(6,403)	TE001960
	WRITE(6,409) (K,FLOWNW(K),FLOWW(K),FLOWBW(K),FLOWF(K),FLOWN(K),	TE001970
	1 K=2,1Y)	TE001980
402	CONTINUE	TE001990
403	FORMAT(//1X,20HY,2X,10H FLOWNW,10H FLOWW,10H FLOWBW,	TE002000
	1 10H FLOWF,10H FLOWN/)	TE002010
	RETURN	TE002020
C		TE002030
C-----	DIFFUSION TERMS.	TE002040
C		TE002050
4100	IF (K0010.NE.41) RETURN	TE002060
	WRITE(6,4130) IX,KOUNT(IX)	TE002070
4130	FORMAT(//1X,53(10=),4H IX=,12,12H, KOUNT(IX)=,13)	TE002080

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IF (INC.LO.-1) GO TO 411	TE002090
WRITE (6,410)	TE002100
WRITE (6,409) (K,DIFN(K),DIFE(K),DIFW(K),DIFEE(K),DIFNE(K),	TE002110
1 K=2,NY)	TE002120
410 FORMAT(//1X,2HY,2X,10H DIFN,10H DIFE,10H DIFW,	TE002130
1 10H DIFEE,10H DIFNE/)	TE002140
GO TO 412	TE002150
411 WRITE (6,413)	TE002160
WRITE (6,439) (K,DIFNW(K),DIFW(K),DIFWW(K),DIFE(K),DIFN(K),	TE002170
1 1=2,NY)	TE002180
412 CONTINUE	TE002190
413 FORMAT(//1X,2HY,2X,10H DIFNW,10H DIFW,10H DIFWW,	TE002200
1 10H DIFE,10H DIFN/)	TE002210
RETURN	TE002220
END	TE002230

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SUBROUTINE PLACT
LOGICAL CHNG
DOUBLE PRECISION A,X,Y
COMMON /INDEX/ IDC0, IDC02, IDF, IDH, IDH2, IDH20, ID0, ID0H, ID02, IDN,
1 IDN0, IDN02, IDN2, IDN20, IEQUIL, IHCP, IFR, JJ, KNTCS, NA, NLM,
2 IS, ISL1, ISL2, HSK, NSM, NS1, NS2, ID(4,15)
3 /PARAMS/ CONVG, EMV, EPSS, GASCON, IDEBUG, ITMAX, PA, SM, TINYK, TK, TLN, TNYR
5 /PLCES/ASUB(20,3), CPSUM, HSUM, HO(14), SMW(14), SO(14), S1(14),
6 S2(14), Z(2,7,14)
7 /EQUIL/AC1, AC2, AC3, AC4, AH1, AH2, AH3, AH4, ASM1, ASM2, ASM3, ASM4,
8 AS1(4,7,2), HDIV, HMAX, HMIN, PEXP(7)
9 /EACS/ BX(15), BX2(15), TACT(15), TACT2(15), TEN(15), TEN2(15)
COMMON /LLANTS/ATOM(3,7), BO(7)
1 /STGCH/ AL(7,14)
2 /MATRIX/ A(14,15), X(15), Y(15)
DIMENSION DATA(12), AT(4), B(4)
RE000010
RE000020
RE000030
RE000040
RE000050
RE000060
RE000070
RE000080
RE000090
RE000100
RE000110
RE000120
RE000130
RE000140
RE000150
RE000160
RE000170
C-----RE000180
CHAPTER 1 1 1 1 1 1 1 1 PRELIMINARIES 1 1 1 1 1 1 1 RE000191
C-----RE000200
DATA ELEM/4HELEM/
DATA RVIS/4HREVE/, THIRD/4HM /
DATA THRM/4HTHR/, AMCH/4HMECH/, BLANK/4H /
DATA TEND/2.302585/, XMAX/0.001/, XMIN/0.00033333/
RE000210
RE000220
RE000230
RE000240
900 READ (5,901) (DATA(I), I=1,12)
RE000250
901 FORMAT (12A4)
RE000260
IF (DATA(1).EQ.BLANK) GO TO 900
RE000270
IF (DATA(1).EQ.ELEM) GO TO 10
RE000280
IF (DATA(1).EQ.THRM) GO TO 20
RE000290
IF (KNTCS.EQ.0) RETURN
RE000300
IF (DATA(1).EQ.AMCH) GO TO 30
RE000310
C-----RE000320
CHAPTER 2 2 2 2 2 2 2 2 ELEMENT DATA 2 2 2 2 2 2 2 RE000330
C-----RE000340
10 NLM=1
RE000350
11 READ (5,10) (ATOM(K,NLM), K=1,2)
RE000360
150 FORMAT (A2,7X,F10,6)
RE000370
IF (ATOM(1,NLM).EQ.BLANK) GO TO 12
RE000380
NLM=NLM+1
RE000390
GO TO 11
RE000400
12 NLM=NLM-1
RE000410
GO TO 900
RE000420
C-----RE000430
CHAPTER 3 3 3 3 3 3 3 3 THERMODYNAMIC DATA 3 3 3 3 3 3 3 RE000440
C-----RE000450
20 NS=1
RE000460
21 READ (5,220) (DATA(I), I=1,3), (AT(J), B(J), J=1,4), T1, T2, NCD
RE000470
220 FORMAT (3A4,12X,4(A2,F3,0),1X,2F10,3,115)
RE000480
IF (DATA(1).EQ.BLANK) GO TO 26
RE000490
READ(5,22) (Z(1,J,NS), J=1,5), NCD
RE000500
222 FORMAT (5E15,8,15)
RE000510
READ(5,22) (Z(1,J,NS), J=6,7), (Z(2,K,NS), K=1,3), NCD
RE000520

```

225 READ (5,225) (7(2,J,NS),J=4,7),NCD	REN00530
FORMAT(4E15.8,T20)	REN00540
DO 22 L=1,NLM	REN00550
22 AL(L,HS)=0.0	REN00560
SUM=0.0	REN00570
DO 24 K=1,4	REN00580
IF (B(K).EQ.0.) GO TO 24	REN00590
DO 25 L=1,NLM	REN00600
IF (ATOM(1,L).NE.AT(K)) GO TO 23	REN00610
AL(L,HS)=AL(L,HS)+B(K)	REN00620
SUM=SUM+ATOM(2,L)*B(K)	REN00630
23 CONTINUE	REN00640
24 CONTINUE	REN00650
SMW(HS)=SUM	REN00660
DO 25 I=1,3	REN00670
25 ASUB(HS,I)=DATA(I)	REN00680
HS=HS+1	REN00690
GO TO 21	REN00700
26 HS=HS-1	REN00710
HSM=HS+1	REN00720
HA=HS+1	REN00730
DO 27 I=1,HS	REN00740
RSMW=1.0/SMW(I)	REN00750
DO 27 J=1,7	REN00760
DO 27 K=1,2	REN00770
27 Z(K,J,I)=Z(K,J,I)*RSMW	REN00780
GO TO 900	REN00790
C-----	
CHAPTER 4 4 4 4 4 4 REACTION MECHANISM DATA 4 4 4 4 4 4	REN00800
C-----	REN00810
30 JJ=1	REN00820
31 READ (5,330) (DATA(I),I=1,12),BX(JJ),TEN(JJ),TACT(JJ),DT1,DT2	REN00830
330 FORMAT (12A4,3F8.3,2A4)	REN00840
IF (DATA(1).EQ.BLANK) GO TO 354	REN00850
IF (DT1.NE.RVRS) GO TO 32	REN00860
J=JJ-1	REN00870
BX2(J)=BX(JJ)	REN00880
TEN2(J)=TEN(JJ)	REN00890
TACT2(J)=TACT(JJ)	REN00900
BX2(J)=10.0*BX2(J)	REN00910
GO TO 34	REN00920
32 BX(JJ)=10.0*BX(JJ)	REN00930
DO 33 I=1,4	REN00940
33 IB(I,JJ)=0	REN00950
HE=1	REN00960
DO 34 N=1,6	REN00970
K=N*2-1	REN00980
IF (DATA(K).EQ.BLANK) GO TO 38	REN00990
IF (DATA(K).NE.THIRD) GO TO 34	REN01000
DATA(K)=BLANK	REN01010
GO TO 34	REN01020
34 DO 35 I=1,HS	REN01030
	REN01040

IF (DATA(K).NE.ASUB(I,1)) GO TO 35	RE001050
IF (DATA(K+1).NE.ASUB(I,2)) GO TO 35	RE001060
I1=I	RE001070
GO TO 34	RE001080
34 CONTINUE	RE001090
35 IF (K.GT.4) GO TO 37	RE001100
IL(HO,J0)=11	RE001110
HL=H0+1	RE001120
GO TO 36	RE001130
36 IF (HO.LT.2) HO=3	RE001140
IL(HO,J0)=11	RE001150
HO=HO+1	RE001160
37 DX=(XMAX-XMIN)+7.142857E-2	RE001170
SUMX=0.0	RE001180
SUMY=0.0	RE001190
INCPS=3	RE001200
NS1=1	RE001210
NS2=NS	RE001220
DO 351 I=1,15	RE001230
X(I)=XMIN+DX*FI DAT(I-1)	RE001240
SUMX=SUMX+X(I)	RE001250
TKINV=X(I)	RE001260
TR=1.0/TKINV	RE001270
TLH=ALOG(*K)	RE001280
CALL NCIS	RE001290
SUM1=0.0	RE001300
DO 350 J0=1,4	RE001310
K=10(HO,J0)	RE001320
IF (K.EQ.0) GO TO 350	RE001330
GF=(HO(K)-SD(K))*SMW(K)	RE001340
IF (HO.LT.3) SUM1=SUM1+GF	RE001350
IF (HO.LT.3) SUM1=SUM1-GF	RE001360
350 CONTINUE	RE001370
SUM1=FXI(SUM1)	RE001380
T=1.0	RE001390
IF (ID(2,J0).EQ.0) TM1=0.082057+TK	RE001400
IF (ID(4,J0).EQ.0) TM1=1.0/(0.082057*TK)	RE001410
AK=BX(J0)	RE001420
IF (TEH(J0).NE.0.0) AK=AK*TK**TEN(J0)	RE001430
IF (TACT(J0).NE.0.0) AK=AK*EXP(-TACT(J0)*TKINV)	RE001440
AF=AK+T-1/SUM1	RE001450
Y(I)=ALOG(AK)	RE001460
351 SUMY=SUMY+Y(I)	RE001470
XBAR=SUMX+6.6666667E-2	RE001480
YBAR=SUMY+6.6666667E-2	RE001490
SUMX=0.0	RE001500
SUM1=0.0	RE001510
SUMY=0.0	RE001520
DO 352 I=1,15	RE001530
SUMX=SUMX+Y(I)+(X(I)-XBAR)	RE001540
SUM1=SUM1+(X(I)-XBAR)**2	RE001550
352 SUMY=SUMY+(Y(I)-YBAR)**2	RE001560

ORIGINAL PAGE IS
OF POOR QUALITY

```
TF02(JJ)=P.0
TACT2(JJ)=-SUMX/SUM1
BX2(JJ)=(YBAR+TACT2(JJ)*XBAR)/TENLN
SUMX=0.1
DO 353 I=1,15
353 SUMX=SUMX+(Y(I)+TACT2(JJ)*X(I)-TENLN*BX2(JJ))*P
SUMY=SQRT(1.-SUMX/SUMY)
SUMX=SQRT(SUMX*7.142857E-2)
BX2(JJ)=14.*BX2(JJ)
JJ=JJ+1
GO TO 31
354 JJ=JJ-1
RETURN
END
```

RE001570
RE001580
RE001590
RE001600
RE001610
RE001620
RE001630
RE001640
RE001650
RE001660
RE001670
RE001680
RE001690
RE001700

ORIGINAL PAGE IS
OF POOR QUALITY

Tr 5=0.25*TK5	HCPS0530
Dr 30 1=-DS1,DS2	HCPS0540
ZK51=Z(K,5,IS)	HCPS0550
ZK41=Z(K,4,IS)	HCPS0560
ZK31=Z(K,3,IS)	HCPS0570
ZK21=Z(K,2,IS)	HCPS0580
ZK11=Z(K,1,IS)	HCPS0590
So(IS)=TK5*ZK51+TK4*ZK41+TK3*ZK31+TK2*ZK21+TK1*ZK11+Z(K,7,IS)	HCPS0600
30 H0(IS)=TK5*ZK51+TK4*ZK41+TK3*ZK31+TK2*ZK21+TK1*ZK11+Z(K,6,IS)*TKINV	HCPS0610
RTU=1	HCPS0620
LED	HCPS0630

LISTING OF DATA CARDS

ELEMENTS

C	12.01115	4.0
H	1.00797	1.0
O	15.9294	-2.0
N	14.0067	0.0

.0001
_0002
_0003
_0004
_0005
_0006

THERMO FOR CH4/AIR COMBUSTION WITH NOX

H	J 3/61N	1.00	0.00	0.00	0.0	300.000	5000.000	_0007
	0.24502678F 01	0.10661458E-03	-0.74653315E-07	0.18796520E-10	-0.10259837F-14			_0008
	0.56116035F 05	0.44487572E 01	0.25030699E 01	-0.21800181F-04	0.54205284E-07			_0009
	-0.56475602F-10	0.20999038E-13	0.56098898E 05	0.41675749E 01				_0010
NO	J 6/63N	1.0	1.00	0.00	0.0	300.000	5000.000	_0011
	0.31889992F 01	0.13382279E-02	-0.52899316E-06	0.95919314E-10	-0.64847928F-14			_0012
	0.98283242F 04	0.67458115E 01	0.40459509E 01	-0.34181783E-02	0.79819174F-05			_0013
	-0.61139254F-08	0.15919072E-11	0.97453867E 04	0.29974976E 01				_0014
NO2	J 9/64N	1.0	2.00	0.00	0.0	300.000	5000.000	_0015
	0.46240759F 01	0.25260330E-02	-0.10609483E-05	0.19879239E-09	-0.13799380F-13			_0016
	0.22899900F 04	0.13324137E 01	0.34589224E 01	0.20647063E-02	0.66866060F-05			_0017
	-0.95556665F-08	0.36195873E-11	0.28152261E 04	0.83116980E 01				_0018
N2O	J12/64N	2.0	1.00	0.00	0.0	300.000	5000.000	_0019
	0.47306662F 01	0.28258264E-02	-0.11558104E-05	0.21263681E-09	-0.14564081F-13			_0020
	0.81617617F 04	-0.17151070E 01	0.26189194E 01	0.86439550E-02	-0.68110612F-05			_0021
	0.22275877F-08	-0.80650276E-13	0.87590078E 04	0.92266451E 01				_0022
N2	J 9/65N	2.0	0.0	0.0	0.0	300.000	5000.000	_0023
	0.28963194F 01	0.15154863E-02	-0.57235275F-06	0.99807385E-10	-0.65223536F-14			_0024
	-0.90586182F 03	0.61615143E 01	0.36748257F 01	-0.12031496F-02	0.23240100F-05			_0025
	-0.63217520F-09	-0.22577253E-12	-0.10611587F 04	0.23580418E 01				_0026
CH4	J 3/61C	1H	400	000	0G	300.000	5000.000	_0027
	0.15027072F 01	0.10416798E-01	-0.39181522E-05	0.67777899F-09	-0.44283706E-13			1_0028
	-0.99787078F 04	0.10707143E 02	0.38261932E 01	-0.39794581E-02	0.24558340E-04			2_0029
	-0.22732926F-07	0.69626957E-11	-0.10144950E 05	0.86690073E 00				3_0030
O2	J 9/65O	2.0	0.0	0.0	0.0	300.000	5000.000	4_0031
	0.36219521F 01	0.73618256E-03	-0.19652214F-06	0.36201556E-10	-0.28945623F-14			_0032
	-0.12019822F 04	0.36150942E 01	0.36255907E 01	-0.18782183E-02	0.70554543E-05			_0033
	-0.67635071F-08	0.21555977E-11	-0.10475225E 04	0.43052769E 01				_0034
CO	J 9/65C	1.0	1.00	0.00	0.0	300.000	5000.000	_0035

_0007
_0008
_0009
_0010
_0011
_0012
_0013
_0014
_0015
_0016
_0017
_0018
_0019
_0020
_0021
_0022
_0023
_0024
_0025
_0026
_0027
1_0028
2_0029
3_0030
4_0031
_0032
_0033
_0034
_0035
_0036

0.29840689F 01	0.14891387E-02	-0.57895678E-06	0.10364376F-09	-0.69353499F-14	0037
-0.14245227F 05	0.63479147E 01	0.37100916E 01	-0.16190964E-02	0.36923584F-05	0038
-0.20319673F-08	0.23953344E-12	-0.14356309E 05	0.29555340E 01		0039
C02	J 9/65C	1.0 2.00 0.00 0.6	300.000	5000.000	0040
0.44608040F 01	0.30981717E-02	-0.12392566E-05	0.22741323E-09	-0.15525948E-13	0041
-0.48961438F 05	-0.98635978E 00	0.24007788E 01	0.87350905E-02	-0.66070861E-05	0042
0.20021860F-08	0.63274039E-15	-0.48377520E 05	0.96951447E 01		0043
H	J 9/65H	1.00 0.00 0.00 0.6	300.000	5000.000	0044
0.25000000E 01	0.0	0.0	0.0	0.0	0045
0.25471625F 05	-0.46011758E 00	0.25000000E 01	0.0	0.0	0046
0.0	0.0	0.25471625E 05	-0.46011758E 00		0047
H2	J 3/61H	2.0 0.0 0.0 0.6	300.000	5000.000	0048
0.31001883F 01	0.51119459E-03	0.52644204E-07	-0.34909964E-10	0.36945341E-14	0049
-0.87738013F 03	-0.19629412E 01	0.30574446E 01	0.26765198E-02	-0.58099149E-05	0050
0.55210343F-08	-0.18122726E-11	-0.98890430E 03	-0.22997046E 01		0051
H20	J 3/61H	2.0 1.00 0.00 0.6	300.000	5000.000	0052
0.27167616F 01	0.29451370E-02	-0.80224368E-06	0.10226681F-09	-0.48472104F-14	0053
-0.29905820F 05	0.66305666E 01	0.40701275E 01	-0.11084499E-02	0.41521130E-05	0054
-0.29637404F-08	0.80702101E-12	-0.30279719E 05	-0.32270038E 00		0055
O	J 6/620	1.00 0.00 0.00 0.6	300.000	5000.000	0056
0.25420580F 01	-0.27550603E-04	-0.31028029E-08	0.45510670F-11	-0.43680494F-15	0057
0.29230801F 05	0.49203072E 01	0.29464263E 01	-0.16381664E-02	0.24210303F-05	0058
-0.16028432F-08	0.38906964E-12	0.29147641E 05	0.29639931E 01		0059
OH	J 3/660	1.0 1.00 0.00 0.6	300.000	5000.000	0060
0.29106417F 01	0.95931627E-03	-0.19441700E-06	0.13756646F-10	0.14224542F-15	0061
0.39353811F 04	0.54423428E 01	0.38375931E 01	-0.10778855E-02	0.96830354F-06	0062
0.18713971F-09	-0.22571089E-12	0.36412820E 04	0.49370009E 00		0063
					0064
					0065

MECHANISM

N	NO		H2	O	10.1760	0.0	0.0	WALD7/74	0066
N	O2		NO	O	6.778	1.0	3172.	WALD7/74	0067
OH	N		H	NO	8.778	0.5	4028.	WALD7/74	0068
H	H2O		OH	H2	10.903	0.0	7553.	WALD7/74	0069
N2O	O		HO	HO	11.000	0.0	15000.	WALD7/74	0070
N2O		M	N2	O	11.000	0.0	25176.	WALD7/74	0071
N	O	M	NO	M	10.806	-0.5			0072
NO2	O		NO	O2	10.000	0.0	300.		0073
NO2	M		O	NO	13.041	0.0	33000.		0074
									0075

APPENDIX C - GLOSSARY OF FORTRAN VARIABLES

Note: A number of Fortran variables, which are used locally in NASCO II, are not listed below. However, the user should be able to derive their meaning from the context in which they are used.

NAME	LOCATION	TYPE	MEANING
A	COEFF	Array	Finite-difference coefficient.
A	CALC	Array	Elements of the correction matrix.
AC1-AC4	BLOCK DATA		Polynomial coefficients for specific heat of equilibrium-product-species.
AE	COEFF	Array	Finite-difference coefficient.
AEDDX	GEOM	Array	Ratio of area to the internodal distance for east face of the cell.
AH1-AH4	BLOCK DATA		Polynomial coefficients for enthalpy of equilibrium-product-species.
AK	BLOCK DATA		Von Karman constant.
AK	REACT		Temporarily stored quantity.
AL	REACT	Array	Atomic stoichiometric coefficients; AL (I,J) is the kg-atoms of element I per kg-mole of species J.
ALNR1I	MAIN		$\ln (r_{1,m}/r_{1,i})$.
ALNR10	MAIN		$\ln (r_{1,0}/r_{1,m})$.
ALNR2I	MAIN		$\ln (r_{2,m}/r_{2,i})$.
ALNR20	MAIN		$\ln (r_{2,0}/r_{2,m})$.
AMCH	REACT		Alphanumeric storage for "MECH".
AN	COEFF	Array	Finite-difference coefficient.
ANDDY	GEOM	Array	Ratio of area to the internodal distance for north face of the cell.

NAME	LOCATION	TYPE	MEANING
AREA	ADJUST		Total flow area normal to the x-direction.
AREAE	GEOM	Array	Area of east face of a continuity cell.
AREAN	GEOM	Array	Area of north face of a continuity cell.
ARG	WALL		Logarithm of argument.
ARGMIN	WALL		Smallest value of ARG.
ARRCON	BLOCK DATA		Arrhenius constant, E/R.
ARSL	COEFF	Array	Sum of absolute values of RSLINE.
AS	COEFF *	Array	Finite-difference coefficient.
ASM1- ASM4	BLOCK DATA	Array	Polynomial coefficients for reciprocal mean molecular weight of equilibrium-product-species.
ASNIP	COEFF	Array	Finite-difference coefficient used in performing SNIP.(see Section 3.3.5).
ASUB	REACT	Array	Molecular symbol for species.
AS1	BLOCK DATA	Array	Polynomial coefficients for concentration of equilibrium-product-species.
AT	REACT	Array	Atomic symbol for species.
ATOM	REACT	Array	For element K, ATOM (1,K) = Atomic symbol; ATOM (2,K) = Atomic weight; ATOM (3,K) = Valence or oxidation state.
AW	COEFF	Array	Finite-difference coefficient.
B	COEFF	Array	Finite-difference coefficient.
BIG	BLOCK DATA		A large number.

NAME	LOCATION	TYPE	MEANING
BLANK	OUTPUT, REACT	.	Alphanumeric storage for 4 blank spaces.
BSNIP	COEFF	Array	Finite-difference coefficient used in performing SNIP. (see Section 3.3.5).
BX	REACT	Array	Arrhenius pre-exponential factor for forward reaction.
BX2	REACT	Array	Arrhenius pre-exponential factor for backward reaction.
C	COEFF	Array	Finite-difference coefficient.
CCHECK	BLOCK DATA		Convergence criterion for sum of residual errors.
CE, CN, CS, CW	COEFF		Convective fluxes (E= east face, N=North face, etc.).
CMIX	BLOCK DATA		Specific heat of mixture.
COND	BLOCK DATA		Thermal conductivity.
CONVG	SPECE		Parameter to indicate convergence of chemical-kinetics solution.
CPR	CHEM		Specific heat of equilibrium-product-species.
CPSUM	HCPS		Specific heat of mixture.
CSNIP	COEFF	Array	Finite-difference coefficient used in performing SNIP. (see Section 3.3.5).
D	COEFF	Array	Finite-difference coefficient.
DATA	OUTPUT	Array	Temporary storage before printout.
DATA	REACT	Array	Temporary storage for reading in data.
DE, DN, DW	COEFF		Diffusion fluxes (E=East face, N=North face, etc.).

NAME	LOCATION	TYPE	MEANING
DELU	ADJUST		Increment in values of U along a line resulting from an overall continuity correction.
DIFE	COEFF	Array	Arrays used to store the diffusion fluxes through the faces of a continuity cell. (E=East, EE=East-east; N=North; NE=North-east; NW=North-west; W=West; WW=West-west face.)
DIFEE	COEFF	Array	
DIFN	COEFF	Array	
DIFNE	COEFF	Array	
DIFNW	COEFF	Array	
DIFW	COEFF	Array	
DIFWW	COEFF	Array	
DP	ADJUST		Pressure increment.
DSNIP	COEFF	Array	Finite-difference coefficient used in performing SNIP. (see Section 3.3.5).
DTEMP	MAIN, CHEM		Fractional temperature increment.
DT1	REACT	}	Quantities used during input of thermochemical data.
DT2	REACT		
DU	COEFF	Array	Influence coefficient used in the correction of u-velocity.
DV	COEFF	Array	Influence coefficient used in the correction of v-velocity.
DXG	GEOM	Array	Difference in the x-coordinate values between two adjacent grid nodes.
DXU	GEOM	Array	Difference in the x-coordinate values between two adjacent u-locations.
DYG	GEOM	Array	Difference in the y-coordinate values between two adjacent grid nodes.
DYV	GEOM	Array	Difference in the y-coordinate values between two adjacent v-locations.
ELEM	REACT		Alphanumeric storage for 'ELEM'.
EL1-EL3	BLOCK DATA		Dimensions of combustor L_1, L_2, L_3 (Fig.1).

NAME	LOCATION	TYPE	MEANING
EMA, EMF	BLOCK DATA		Mass flow rates of air and fuel at inlet.
EMIS10 EMIS2I EMIS2O EMISXI EMISXO	BLOCK DATA		Emissivities: 10=Outer surface of inner wall; 2I=inner surface of outer wall; 2O=Outer surface of outer wall; XI=inner surface of end wall; XO=outer surface of end wall.
EMU	MAIN	Array	Effective viscosity.
EMUREF	BLOCK DATA		Reference viscosity (=laminar viscosity).
EMUT	MAIN		Turbulent viscosity.
EMV	CHEM		Total convective and diffusive mass inflow to a cell.
ENTH	MAIN, CHEM		Enthalpy.
ENTHB	MAIN		Enthalpy of B-stream.
ENTHC	MAIN		Enthalpy of C-stream.
EPSS	BLOCK DATA		Convergence criterion for species concentrations.
EPST	BLOCK DATA		Convergence criterion for temperature.
EQRAT	OUTPUT		Equivalence ratio.
ER	WALL		EWALL* Reynolds number.
ESMASS	SOURCE		Source term for continuity equation.
ETA	SPECE		Under-relaxation parameter.
ETA1	SPECE		Under-relaxation parameter.
EWALL	BLOCK DATA		Constant in wall function.
F	MAIN	Array	An array used to store all the dependent and auxiliary variables.
FACTOR	MAIN		Temporarily stored quantity.

NAME	LOCATION	TYPE	MEANING
FFU	MAIN, CHEM		Mass fraction of fuel.
FJF	SOURCE		Mass fraction of fuel.
FJP	CHEM		Mixture fraction.
FLOB	MAIN		Flow rate in B-stream.
FLOC	MAIN		Flow rate in C-stream.
FLOWE FLOWEE	FLOWM FLOWM	Array } Array }	Convective fluxes through the east and east-east faces of a finite-difference cell.
FLOWIN	MAIN		Total inlet mass flow rate (air+fuel).
FLOWN FLOWNE FLOWNW	FLOWM FLOWM FLOWM	Array } Array } Array }	Convective fluxes through the north, north-east and north-west faces.
FLOWST	ADJUST		Mass flow rate based on the starred velocities.
FLOWUP	ADJUST		Mass flow rate through the plane upstream (in the sweep direction) of the one being considered.
FLOWW FLOWWW	FLOWM FLOWM	Array } Array }	Convective fluxes through the west and west-west faces.
FM	MAIN	Array	Mixture fraction.
FN2	CHEM		Nitrogen mass fraction.
FO2	CHEM		Mass fraction of oxygen.
FPR	CHEM		Mass fraction of equilibrium-product-species.
FS	MAIN	Array	Mass fractions of species.
FSII	CHEM		Temporary storage for FS.

NAME	LOCATION	TYPE	MEANING
FSTOIC	MAIN	Array	Stoichiometric mixture fraction.
FSTOIM	MAIN		1.0 - FSTOIC.
FUB	BLOCK DATA		Fuel mass-fraction in B-stream.
FUBRNT	SOURCE		Fuel mass-fraction in fully-burnt gas.
FUC	BLOCK DATA		Fuel mass-fraction in C-stream.
FUE	MAIN		Unburnt fuel mass fraction.
FUEX	SOURCE		Excess fuel.
GASCON	BLOCK DATA		Universal gas constant.
GAZ	REACT		Alphanumeric storage for 'G' (for gas).
GF	REACT		Temporarily stored quantity.
H	MAIN	Array	Stagnation enthalpy.
HDIV	BLOCK DATA		Intermediate enthalpy value for the coefficients AS1.
HFU	BLOCK DATA		Heat of combustion of fuel.
HMAX	BLOCK DATA		Maximum enthalpy value for the coefficients AS1.
HMIN	BLOCK DATA		Minimum enthalpy value for the coefficients AS1.
HMIX	CHEM		Mixture enthalpy.
HPR	CHEM		Enthalpy of equilibrium-product-species.
HSUM	MAIN		Enthalpy of mixture.
HO	MAIN		Enthalpy of species.
HW	BLOCK DATA		Recovery factor.

NAME	LOCATION	TYPE	MEANING
I			Index, generally used to define the storage location of a variable (other than v or p) at a given grid node.
ICONST			=IX2NY2-1.
ID	REACT		ID (K,J) is the species index number of species K in reaction J.
IDASH	COEFF		Index in back-substitution for TDMA.
IDCO	BLOCK DATA		Index for CO.
IDCO2	BLOCK DATA		Index for CO2.
IDDEBUG	BLOCK DATA		Index for chemical-kinetics diagnostic output; =0, no output; =1, output obtained.
IDF	BLOCK DATA		Index for fuel.
IDH	BLOCK DATA		Index for H.
IDH2	BLOCK DATA		Index for H2.
IDH2O	BLOCK DATA		Index for H2O.
IDN	BLOCK DATA		Index for N.
IDNO	BLOCK DATA		Index for NO.
IDNO2	BLOCK DATA		Index for NO2.
IDN2	BLOCK DATA		Index for N2.
IDN2O	BLOCK DATA		Index for N2O.
IDO	BLOCK DATA		Index for O.
IDOH	BLOCK DATA		Index for OH.
IDO2	BLOCK DATA		Index for O2.

NAME	LOCATION	TYPE	MEANING
IE, IN INE, INW, etc.,			Storage locations for neighbouring nodes around the one corresponding to the storage location I or IV; IE for the eastern one, INW for the north-western one, and so on.
IEP			Storage location for p-node at the east of the one corresponding to IP.
IEQUIL	BLOCK DATA		=0, equilibrium concentrations not obtained. =1, equilibrium concentrations obtained.
IEW	CONST	Array	The number of nodes in the r-direction at which values of a dependent variable are stored.
IHCPS	MAIN		Index to control calculation of thermodynamic properties.
ILAST	CONST	Array	The last location in the F-array for a given variable.
IMAT	SPECE		Number of rows in Newton -Raphson correction matrix.
IMON	CONST	Array	Index to denote the grid node (IXMON, IYMON) for use in monitoring the progress of the iterative solution.
INC	MAIN		=1, sweep in positive x-direction; =-1, sweep in negative x-direction.
INERT	BLOCK DATA		Indicator of chemically-inert/reacting flow: =1, Chemically inert; =2, Chemically reacting.
IP			Index used to define the storage location of a p-node.
IPLRS	BLOCK DATA		Number of sweeps after which residual errors are printed out.
IPR	BLOCK DATA		Index number for products.

NAME	LOCATION	TYPE	MEANING
IPREF	CONST		Index used to define the storage location of the reference-pressure node.
IPRINT	BLOCK DATA		Index to control type of printout required, i.e. field values of dependent variables are printed after every IPRINT iterative sweeps.
ISNIP	MAIN		=0, SNIP is performed; =1, SNIP is not performed (See Section 3.3.5)
ISWEEP	MAIN		Variable counter for the iteration sweep number.
IT	MAIN, CHEM		Number of iterations on temperature.
ITER	SPECE		Number of iterations during chemical-kinetics computations.
ITMAX	BLOCK DATA		Maximum number of iterations of chemical-kinetics computations.
IV			Index used to define the storage location of a v-velocity node.
IVE, IVN IVS, etc			Storage locations for neighbouring v-nodes around the one corresponding to IV - IVE for eastern one; IVN for northern one; and so on.
IX			The grid-line number for an X-constant line on which variables are being updated.
IX1NY	MAIN		$= (IX-1) * NY.$
IX1NY1	MAIN		$= (IX-1) * NYM1.$
IX2NY2	MAIN		$= (IX-2) * NYM2.$
IX1NYU	MAIN		$= (IXU-1) * NY.$
IX2NYU	MAIN		$= (IXU-2) * NYM2.$

NAME	LOCATION	TYPE	MEANING
IXMON, IYMON	BLOCK DATA		(IXMON, IYMON) is the location of the grid node at which values of the variables are printed out at each iteration for monitoring the numerical process.
IXNY	CONST	Array	Variable to facilitate computing the location in the storages for the variable denoted by J at a grid node on the line where variables are being updated. For example, $I = IY + IXNY(JV)$ gives the storage location, I, in the V-array at the grid node (IX,IY), IX having been included into IXNY (JV).
IXP1	MAIN		$=IX+1$.
IXPREF IYPREF	BLOCK DATA		(IXPREF, IYPREF) is the location of the grid node where the pressure is taken as the reference value.
IXU	MAIN		IX-location of u-velocity currently being solved for.
IXUP1	MAIN		$IXU+1$.
IXW	BLOCK DATA		Index denoting end of inner tube in x-direction.
IY			An index used to denote the (IY)th grid node on the line where variables are being updated.
IYF, IYL	MAIN		The first and last IY-locations in the domain of integration.
IYFM1	MAIN		$=IYF-1$.
IYFP1	MAIN		$=IYF+1$.
IYFUEL	BLOCK DATA		IY location of incoming fuel stream.
IYLM1	MAIN		$=IYL-1$.
IYLP1	MAIN		$=IYL+1$.
IYM1			$=IY-1$.

NAME	LOCATION	TYPE	MEANING
IYW	BLOCK DATA		Index denoting location of inner tube in y-direction.
IYWM1	MAIN		=IYW-1.
IYWP1	MAIN		=IYW+1.
IZERO	CONST	Array	The location in the F-array that is immediately in front of the first of the storages for the variable denoted by J.
JEMU	BLOCK DATA		Index for effective viscosity.
JFM	BLOCK DATA		Index for mixture fraction.
JFUE	BLOCK DATA		Index for unburnt fuel mass fraction.
JH	BLOCK DATA		Index for stagnation enthalpy.
JJ	REACT		Number of chemical reactions.
JLAST	BLOCK DATA		Maximum index number for variables stored in F-array.
JP	BLOCK DATA		Index for pressure.
JPHI			Index for general variable ϕ .
JPP	BLOCK DATA		Index for pressure-correction.
JRHO	BLOCK DATA		Index for density.
JS1, JS2	BLOCK DATA		Indices for first and last chemical species in F-array.
JTEM	BLOCK DATA		Index for temperature.
JU, JV	BLOCK DATA		Indices for u and v velocities.
KASE			Index denoting problem.
KGOTO			Index used in a subroutine argument list to access the appropriate part of the subroutine on any call.

NAME	LOCATION	TYPE	MEANING
KINPRI	BLOCK DATA		Control index for print-out of initially assigned values of variables in field, =0, of no print-out of these needed; =1, if print-out wanted.
KLT	BLOCK DATA		Index to denote type of flow; i.e. laminar (1) or turbulent (2).
KMAT	SPECE		IMAT + 1.
KNTCS	BLOCK DATA		=0, chemical-kinetics computations suppressed; =1, chemical-kinetics computations performed.
KOUNT	MAIN	Array	An array used to store for each TDMA line the maximum number of TDMA traverses made, this number being. LE. NTDMA.
KRAD	BLOCK DATA		Control index for cartesian or cylindrical polar (axisymmetrical) coordinates, =1 for cartesian; =2 for cylindrical polar.
KRHOMU	CONST		=KSOLVE (JRH0) + KSOLVE (JEMU).
KSOLVE	BLOCK DATA	Array	Control index to govern whether the variable denoted by J requires updating in the numerical process, J covering the whole range of variables under the F-array; =0, if not to be updated; =1, if updating required.
KSWEET	BLOCK DATA		Number of sweeps after which chemical-kinetics computations are started.
KTEST	BLOCK DATA		Control index for diagnosing print out levels; =0, if no such print-out is required; =1, prints out the following geometrical quantities related to the grid, variable information initial values assigned in the field;

NAME	LOCATION	TYPE	MEANING
LABPHI			=2 prints out those for 1 and the following - starred velocities and velocity residual-sources on the TDMA line, also quantities related to the overall mass-continuity adjustment and the cell- wise-continuity correction; =3 prints out those for 2 and the coefficients in the general form of the finite-difference equation for all the dependent variables.
LPHI LSWEEP	BLOCK DATA		A variable for transferring the value of JPHI from one subroutine to another one that does not have JPHI as an argument. Index for general variable ϕ . Maximum number of iterative sweeps to be performed.
MODE	CALC		Type of reaction.
NA	SPECE		NS + 1.
NCD	REACT		Index used during input of thermo- chemical data.
ND	REACT		Index during computation of ID.
NLM	REACT		Number of elements.
NS	BLOCK DATA		Number of chemical species.
NSE1	BLOCK DATA		Index for first equilibrium-product- species.
NSE2	BLOCK DATA		Index for the last equilibrium-product- species.
NSK	BLOCK DATA		Number of species whose concentrations are kinetically determined.
NSK1	CALC		NSK + 1.
NSM	REACT		NS + 1.
NSOLVE	BLOCK DATA		Number of variable equations to be solved.

NAME	LOCATION	TYPE	MEANING
NS1 NS2	MAIN MAIN	}	First and last species numbers for computation of thermodynamic properties.
NTDMA	BLOCK DATA		Maximum number of TDMA traverses along any one grid line.
NTMAX	BLOCK DATA		Maximum number of iterations on temperature.
NTRAV	MAIN		The number of traverses being performed on a line at any sweep.
NUMCOL	BLOCK DATA		Number of columns to be printed out.
NX	BLOCK DATA		Number of X-constant grid lines in the flow domain.
NXMAX	BLOCK DATA		Maximum number of X-constant grid lines that can be used to cover the flow domain without changing the dimensions of the variable arrays.
NXM1 NXM2	CONST CONST		=NX-1. =NX-2.
NXYG	CONST		=NX * NY, is the total number of locations where scalar quantities other than pressures are stored.
NXYP	CONST		=(NX-2)*(NY-2), is the total number of locations where pressure values are stored. (Pressure values at flow boundaries are not stored).
NXYU	CONST		=(NX-1)*NY, is the total number of locations where the X- component velocity values, U, are stored.
NY	BLOCK DATA		Number of Y-constant grid lines in the flow domain.

NAME	LOCATION	TYPE	MEANING
NYMAX	BLOCK DATA		Maximum number of Y-constant grid lines that can be used to cover the flow domain without changing the dimensions of the variable arrays.
NYM1	CONST		=NY-1.
NYM2	CONST		=NY-2.
OXB	BLOCK DATA		Oxygen mass-fraction in B-stream.
OXBRNT	MAIN		Oxygen mass-fraction in fully-burnt gas.
OXC	BLOCK DATA		Oxygen mass-fraction in C-stream.
P.	MAIN	Array	Pressure.
PA	CHEM		Pressure.
PDGSCN	MAIN, CHEM		Pressure + Gas constant.
PEXP	BLOCK DATA	Array	Exponent on pressure in chemical-equilibrium calculations.
PHAZ	REACT		Phase of species for which thermochemical data is read.
PHI	CHEM		Temporary storage for $(f-f_{st})/(1-f_{st})$.
PP	COEFF	Array	Pressure-correction.
PRB	MAIN		Mass fractions of (products +N2) in B-stream.
PRC	MAIN		Mass fractions of (products +N2) in C-stream.
PREEXP	BLOCK DATA		Arrhenius pre-exponential factor.
PREFF	MAIN	Array	Effective Prandtl/Schmidt number.
PRESS	BLOCK DATA		Pressure.

NAME	LOCATION	TYPE	MEANING
PRL	BLOCK DATA	Array	Laminar Prandtl/Schmidt number.
PRT	BLOCK DATA	Array	Turbulent Prandtl/Schmidt number.
R	GEOM	Array	Radius.
RDXG	GEOM	Array	Reciprocal of DXG.
RDXU	GEOM	Array	Reciprocal of DXU.
RDYG	GEOM	Array	Reciprocal of DYG.
RDYV	GEOM	Array	Reciprocal of DYV.
RECTK	CALC		Reciprocal of TK.
RELAXP	BLOCK DATA		Under-relaxation factor for pressure.
REMI			=1.0/EMIS2I-1.0.
REY	WALL		Reynolds number.
RF	BLOCK DATA		Radius of incoming fuel jet.
RFSTM	MAIN		1.0/FSTOIM.
RHDIFF	CHEM		Reciprocal of (HMAX-HMIN).
RHO	MAIN	Array	Density.
RHOB	MAIN		Density of B-stream.
RHOC	MAIN		Density of C-stream.
RHOINF	BLOCK DATA		Density of surroundings.
RHOP	CALC		Density.
RHOREF	MAIN		Reference density.
RHSM	CALC		Density ÷ Molecular weight.
RHSMP	CALC		RHSM* Density.

NAME	LOCATION	TYPE	MEANING
RHSM SQ	CALC		RHSM* square of density.
RHSQ	CALC		Square of density.
RPREFF	COEFF		Reciprocal of Prandtl/Schmidt number.
RSLINE	COEFF	Array	Algebraic sum of residual-sources at a given line for a given variable.
RSCHK	BLOCK DATA		Convergence criterion for residuals at a line.
RSMAX	COEFF		Largest of the magnitudes of residual-source sums of all the variables.
RSMW	REACT		Reciprocal of SMW.
RSREF	MAIN	Array	Normalising factors for residual-errors.
RSSUM	COEFF	Array	Sum of residual sources for a given variable.
RSXG	GEOM	Array	Reciprocal of SXG.
RSXU	GEOM	Array	Reciprocal of SXU.
RSYG	GEOM	Array	Reciprocal of SYG.
RSYV	GEOM	Array	Reciprocal of SYV.
RV	GEOM	Array	r-coordinates of the v-nodes.
RVCB	GEOM	Array	r-coordinates of the v-cell.
RVSQ	GEOM	Array	Square of RV.
RVRS	REACT		Alphanumeric storage for 'REVE'.
R1	CALC		Forward reaction rate.
R1I	BLOCK DATA		Inner radius of inner tube.
R1O	BLOCK DATA		Outer radius of inner tube.

NAME	LOCATION	TYPE	MEANING
R2	CALC		Backward reaction rate.
R2I	BLOCK DATA		Inner radius of outer tube.
R2M	MAIN		$=0.5 \cdot (R2I + R20)$.
R20	BLOCK DATA		Outer radius of outer tube.
S	WALL, SOURCE		Shear stress coefficient.
SHALF	WALL, SOURCE		Square root of S.
SHALF1	WALL, SOURCE		Square root of S.
SIGMA	BLOCK DATA		Stefan-Boltzmann constant.
SM	REACT		Reciprocal of mean molecular weight of mixture.
SMW	REACT	Array	Molecular weight of species.
SP	SOURCE	Array	Part of linearised source term.
SP1	CHEM		STOICH + 1.0.
STOICH	BLOCK DATA		Stoichiometric ratio.
STORE		Array	Used for temporarily stored quantities.
STXI	BLOCK DATA		Stanton number at inner surface of end wall.
STX 0	BLOCK DATA		Stanton number at outer surface of end wall.
ST1I	BLOCK DATA		Stanton number at inner surface of inner tube.
ST10	BLOCK DATA		Stanton number at outer surface of inner tube.
ST2I	BLOCK DATA		Stanton number at inner surface of outer tube.

NAME	LOCATION	TYPE	MEANING
ST20	BLOCK DATA		Stanton number at outer surface of outer tube.
SU	SOURCE	Array	Part of linearised source term.
SUMX	REACT		Sum of x's*.
SUMY	REACT		Sum of y's*.
SUM1	REACT		Temporarily stored quantity.
SXG	GEOM	Array	The x-direction length of a ϕ -cell.
SXU	GEOM	Array	The x-direction length of a u-cell.
SYG	GEOM	Array	The r-direction length of a ϕ -cell.
SYV	GEOM	Array	The r-direction length of a v-cell.
S0	HCPS	Array	One-atmosphere, ideal gas entropy of species.
S1	CHEM	Array	Species mole-numbers averaged over four neighbouring nodes.
S2	CHEM	Array	Species mole-number.
TACT	REACT	Array	Activation temperature (E/R) for forward reaction.
TACT2	REACT	Array	Activation temperature (E/R) for backward reaction.
TB	BLOCK DATA		Temperature of B-stream.
TC	BLOCK DATA		Temperature of C-stream.
TEM	MAIN	Array	Absolute temperature.
TEN	REACT	Array	Exponent on temperature in forward reaction rate expression.
TENLN	REACT		$\ln(10)$.

*x and y are used for temporary storage of some quantities in subroutine REACT.

NAME	LOCATION	TYPE	MEANING
TEN2	REACT	Array	Exponent on temperature in backward reaction rate expression.
THIRD	REACT, OUTPUT		Alphanumeric storage for 'M' (third body in chemical reaction).
THRM	REACT		Alphanumeric storage for 'THER'.
TINY	BLOCK DATA		A small number.
TINYK	BLOCK DATA		A small number for chemical-kinetics calculations.
TITLE	BLOCK DATA	Array	Alphanumeric storage to identify a dependent variable.
TK	CHEM		Temperature.
TK1.. TK5	HCPS		Temporarily stored quantities.
TLN	REACT		$\ln$ (temperature).
TMAX	BLOCK DATA		Maximum temperature in the calculations.
TMIN	BLOCK DATA		Minimum temperature in the calculations.
TM1	REACT		Temporarily stored quantity.
TM1	CALC		R1 - R2.
TM2.. TM5	HCPS		Temporarily stored quantities.
TNY	BLOCK DATA		$\ln$ (TINYK).
TST1	SPECE		Temporarily stored quantity.
T1	SOURCE		Temporarily stored quantity (=PREEXP*PRESS**2).
T1 T2	REACT REACT	}	Quantities used during input of thermochemical data.

NAME	LOCATION	TYPE	MEANING
U	MAIN	Array	Longitudinal velocity component.
UB	BLOCK DATA		Velocity of B-stream.
UC	BLOCK DATA		Velocity of C-stream.
UINF	BLOCK DATA		Free stream u-velocity.
V	MAIN	Array	Radial velocity component.
VINF	BLOCK DATA		Free stream v-velocity.
VMIX	MAIN		Specific volume of mixture.
VOL	GEOM	Array	Volume of a finite-difference cell.
WAREA	MAIN		$=0.5(R20^{**2} - R2I^{**2})$.
WB	MAIN		Reciprocal molecular weight of B-stream.
WC	MAIN		Reciprocal molecular weight of C-stream.
WMIX	BLOCK DATA		Molecular weight of mixture.
X	BLOCK DATA	Array	x-coordinates of the ϕ -nodes.
X	CALC	Array	Corrections in chemical-kinetics calculations.
XBAR	REACT		Average value of X.
XMAX	REACT		Maximum x-value.
XMIN	REACT		Minimum x value.
XU	GEOM	Array	x-coordinates of the u-nodes.
Y	BLOCK DATA	Array	r-coordinates of the ϕ -nodes.
Y	SPECE	Array	Logarithms of species mole-numbers.
YBAR	REACT		Average value of Y.

NAME	LOCATION	TYPE	MEANING
YV	GEOM	Array	r-coordinates of the v-nodes.
Z	REACT	Array	Coefficients for calculation of thermo-chemical data.
ZK1I... ZK5I	HCPS		Temporarily stored quantities.

APPENDIX D

LISTING OF THE OUTPUT FROM THE NASCO II PROGRAM

Interpretation of the Output from NASCO II

In this section the details of the output supplied with this report are provided to enable the reader to understand the output.

The first item of print-out gives details of the problem specifying parameters, and is self-explanatory.

The second item of print-out specifies the initial guessed fields of the dependent variables. Each field variable ϕ is given in a table of the following form:

-----FIELD VARIABLE (ϕ) -----

y locations of
grid for which
value is printed



x locations of
grid for which
value is printed



This item of printout is repeated at every IPRINT iterative sweeps; odd-numbered sweeps refer to sweeps in the positive-x direction and even numbered sweeps to sweeps in the negative-x direction.

The third item of print-out gives details of the residuals along lines for the dependent variables, and also the sums of the absolute values of these residuals for the whole field.

The residuals are normalised over-all balance quantities, departures of which from zero give information about the extent to which errors in the finite-difference equations remain to be eliminated. For details the reader is advised to refer to Appendix D of Reference 1.

The fourth item of printout gives the values of the dependent variables at a particular monitoring location; in the present output at the node (3,3).

PREDICTION OF HYDRODYNAMICS AND
CHEMISTRY OF A TWO-CONCENTRIC-TUBE
COMBUSTOR WITH ATTENTION
TO POLLUTANT FORMATION

THE NASCO II COMPUTER PROGRAM
PREPARED BY
CONCENTRATION, HEAT AND MOMENTUM LTD.
FOR
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
NASA LEWIS RESEARCH CENTER

CONTRACT NASW-3077

APRIL 1978

RESULTS FOR TEST CASE 2
S.I. UNITS ARE USED THROUGHOUT

FLOW CONDITIONS

=====

TURBULENT, KLT=2

CHEMICALLY REACTING, INERT=2

GEOMETRY

=====

RF	R1I	R1O	R2I	R2O
1.00E-03	3.00E-03	3.50E-03	9.00E-03	1.05E-02
EL1	EL2			
2.00E-01	1.00E-02			

INLET CONDITIONS

=====

FLOW RATE OF FUEL, EMF	1.400E-05
FLOW RATE OF AIR, EMA	3.600E-04
VELOCITY OF FUEL STREAM, UB	3.176E+00
VELOCITY OF AIR STREAM, UC	5.677E+00
TEMPERATURE OF FUEL STREAM, TB	2.750E+02
TEMPERATURE OF AIR STREAM, TC	2.750E+02
INLET PRESSURE, PRESS	2.000E+05
REYNOLDS NUMBER	4.409E+03
OVERALL EQUIVALENCE RATIO, EQRAT	6.705E-01
TOTAL MASS FLOW RATE, FLOWIN	5.952E-05

ORIGINAL PAGE IS
OF POOR QUALITY

POLYNOMIAL COEFFICIENTS FOR THERMODYNAMIC PROPERTIES.
 14 COEFFICIENTS ((2(K,J,I),J=1,7),K=1,2) FOR EACH SPECIES I.

N	1.749E-01	7.612E-06	-5.330E-09	1.342E-12	-7.325E-17	4.006E+03
	3.176E-01	1.787E-01	-1.556E-06	3.870E-09	-4.032E-12	1.499E-15
	4.005E+03	2.975E-01				
NO	1.063E-01	4.460E-05	-1.763E-08	3.197E-12	-2.161E-16	3.275E+02
	2.248E-01	1.348E-01	-1.139E-04	2.660E-07	-2.030E-10	5.305E-14
	3.248E+02	9.990E-02				
NO2	1.005E-01	5.491E-05	-2.306E-08	4.321E-12	-3.000E-16	4.978E+01
	2.896E-02	7.519E-02	4.488E-05	1.453E-07	-2.077E-10	7.868E-14
	6.119E+01	1.807E-01				
N2O	1.075E-01	6.420E-05	-2.626E-08	4.831E-12	-3.309E-16	1.854E+02
	-3.897E-02	5.950E-02	1.964E-04	-1.548E-07	5.061E-11	-1.832E-15
	1.990E+02	2.096E-01				
N2	1.034E-01	5.410E-05	-2.043E-08	3.563E-12	-2.328E-16	-3.234E+01
	2.199E-01	1.312E-01	-4.313E-05	8.296E-08	-2.257E-11	-8.059E-15
	-3.788E+01	8.418E-02				
CH4	9.367E-02	6.493E-04	-2.442E-07	4.225E-11	-2.760E-15	-6.220E+02
	6.674E-01	2.385E-01	-2.480E-04	1.531E-06	-1.417E-09	4.340E-13
	-6.324E+02	5.404E-02				
O2	1.132E-01	2.301E-05	-6.142E-09	1.131E-12	-9.046E-17	-3.756E+01
	1.130E-01	1.133E-01	-5.870E-05	2.205E-07	-2.114E-10	6.736E-14
	-3.274E+01	1.345E-01				

CO
1.065E-01 5.316E-05 -2.067E-08 3.700E-12 -2.476E-16 -5.086E+02
2.266E-01 1.325E-01 -5.780E-05 1.318E-07 -7.254E-11 8.552E-15
-5.125E+02 1.055E-01

CO2
1.014E-01 7.040E-05 -2.016E-08 5.167E-12 -3.528E-16 -1.113E+03
-2.241E-02 5.455E-02 1.985E-04 -1.501E-07 4.549E-11 1.430E-17
-1.099E+03 2.203E-01

H
2.480E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 2.527E+04
-4.565E-01 2.480E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
2.527E+04 -4.565E-01

H2
1.538E+00 2.536E-04 2.611E-08 -1.732E-11 1.833E-15 -4.352E+02
-9.737E-01 1.517E+00 1.328E-03 -2.882E-06 2.739E-09 -8.990E-13
-4.905E+02 -1.141E+00

H2O
1.508E-01 1.635E-04 -4.453E-08 5.677E-12 -2.691E-16 -1.660E+03
3.681E-01 2.259E-01 -6.153E-05 2.305E-07 -1.645E-10 4.480E-14
-1.681E+03 -1.791E-02

O
1.589E-01 -1.722E-06 -1.939E-10 2.845E-13 -2.730E-17 1.827E+03
3.075E-01 1.842E-01 -1.024E-04 1.513E-07 -1.002E-10 2.432E-14
1.822E+03 1.853E-01

OH
1.711E-01 5.641E-05 -1.143E-08 8.089E-13 8.364E-18 2.314E+02
3.200E-01 2.256E-01 -6.338E-05 5.693E-08 1.100E-11 -1.327E-14
2.141E+02 2.903E-02

ORIGINAL PAGE IS
OF POOR QUALITY

REACTION MECHANISM

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1. N + NO = N2 + O
2. N + O2 = NO + O
3. OH + N = H + NO
4. H + N2O = OH + N2
5. N2O + O = NO + NO
6. N2O + + M = N2 + O + M
7. N + O + M = NO + + M
8. NO2 + O = NO + O2
9. NO2 + + M = O + NO + M
  
```

RATE CONSTANT PARAMETERS

RATE CONSTANT = $A \cdot T^{**} B \cdot \exp(-TACT/T)$

(T=TEMPERATURE)

FORWARD RATE

BACKWARD RATE

	A	B	TACT	A	B	TACT
1.	1.500E+10	0.000E+00	0.000E+00	6.753E+10	0.000E+00	3.786E+04
2.	5.998E+06	1.000E+00	3.172E+03	5.857E+09	0.000E+00	2.087E+04
3.	5.998E+08	5.000E-01	4.028E+03	1.102E+11	0.000E+00	2.898E+04
4.	7.998E+10	0.000E+00	7.553E+03	3.842E+09	0.000E+00	4.047E+04
5.	1.000E+11	0.000E+00	1.500E+04	2.895E+09	0.000E+00	3.422E+04
6.	1.000E+11	0.000E+00	2.518E+04	2.678E+06	0.000E+00	6.573E+03
7.	6.397E+10	-5.000E-01	0.000E+00	4.600E+12	0.000E+00	7.488E+04
8.	1.000E+10	0.000E+00	3.000E+02	3.186E+09	0.000E+00	2.393E+04
9.	1.099E+13	0.000E+00	3.300E+04	1.532E+08	0.000E+00	-2.950E+03

NX	NY	NXMAX	NYMAX
10	10	25	20

NTDMA	LSWEEP	RSCHEK	CCHECK
3	150	1.00E-02	5.00E-03

FIELD VALUES OF	U	U	U	U	U	U	U	U	U	U
Y(10)=9.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(9)=8.000E-03	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	0.00E+00
Y(8)=6.750E-03	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	0.00E+00
Y(7)=4.750E-03	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	0.00E+00
Y(6)=3.750E-03	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	0.00E+00
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(4)=2.750E-03	5.68E+00	5.68E+00	5.68E+00	5.68E+00	5.68E+00	5.68E+00	5.68E+00	5.68E+00	5.68E+00	0.00E+00
Y(3)=1.500E-03	5.68E+00	5.68E+00	5.68E+00	5.68E+00	5.68E+00	5.68E+00	5.68E+00	5.68E+00	5.68E+00	0.00E+00
Y(2)=5.000E-04	3.18E+00	3.18E+00	3.18E+00	3.18E+00	3.18E+00	3.18E+00	3.18E+00	3.18E+00	3.18E+00	0.00E+00
Y(1)=0.000E+00	3.18E+00	3.18E+00	3.18E+00	3.18E+00	3.18E+00	3.18E+00	3.18E+00	3.18E+00	3.18E+00	0.00E+00
XU(IX)	1= 0.000	2= 0.050	3= 0.095	4= 0.145	5= 0.179	6= 0.192	7= 0.200	8= 0.205	9= 0.210	

FIELD VALUES OF	0	1	2	3	4	5	6	7	8	9	10
Y(10)=9.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(9)=8.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(8)=7.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(7)=7.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(6)=3.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(4)=2.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(3)=1.500E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(2)=5.000E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(1)=0.000E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210	

FIELD VALUES OF	OH	OH	OH	OH	OH	OH	OH	OH	OH	OH	OH	OH
Y(10)=9.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(9)=8.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(8)=6.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(7)=4.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(6)=3.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(4)=2.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(3)=1.500E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(2)=5.000E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(1)=0.000E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210		

[illegible]

X(IX) 1= 0.000 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207 10= 0.210

X(IX) 2= 0.050 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207

X(IX) 1= 0.000 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207 10= 0.210

255

FILE VALUES OF	1	2	3	4	5	6	7	8	9	10
Y(1)=9.000E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(2)=8.000E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(3)=6.750E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(4)=4.750E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(5)=3.750E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(6)=3.250E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(7)=2.750E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(8)=1.500E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(9)=5.000E-04	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(10)=0.000E+00	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
X(JX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.180	7= 0.197	8= 0.202	9= 0.207	10= 0.210

SUM OF ABS. VALUES OF ESTIMATE (X, Y, Z) -

ISWEEP	U	V	ENTH	FM	FUEL	PP
1	1.91E+01	2.01E+00	2.02E+00	3.50E-03	5.69E-02	1.15E+01
2	3.15E+00	6.90E-01	1.70E-01	8.10E-05	1.58E-02	4.72E+00
3	7.00E+00	8.66E-01	1.13E-01	8.47E-05	4.42E-02	8.34E+00
4	2.81E-01	3.31E-01	6.15E-02	6.97E-06	2.40E-03	3.91E+00
5	6.68E-02	2.76E-01	2.11E-01	5.28E-05	1.81E-04	2.95E+00
6	1.24E-01	1.09E-01	1.16E-02	1.62E-05	1.02E-03	1.80E+00
7	3.92E-03	7.21E-02	1.33E-02	6.24E-06	5.39E-06	1.18E+00
8	5.74E-02	2.77E-02	1.98E-02	4.12E-06	2.34E-03	8.45E-01
9	8.83E-04	3.53E-02	5.89E-03	1.32E-06	4.41E-06	7.36E-01
10	2.78E-02	2.32E-02	8.10E-03	1.45E-06	3.61E-03	5.44E-01
11	1.11E-03	2.65E-02	3.58E-03	5.91E-07	1.62E-06	5.13E-01
12	1.47E-02	2.58E-02	4.55E-03	9.08E-07	8.18E-03	4.39E-01
13	1.26E-03	1.90E-02	1.04E-02	2.92E-07	6.97E-07	3.55E-01
14	2.44E-02	3.36E-02	6.86E-03	6.56E-07	8.91E-03	5.24E-01
15	1.95E-03	1.37E-02	7.82E-03	3.23E-07	5.28E-07	2.45E-01
16	7.01E-03	1.49E-02	1.10E-02	8.16E-06	9.75E-05	2.68E-01
17	9.69E-04	8.21E-03	1.33E-02	1.49E-07	2.51E-07	1.72E-01
18	7.35E-03	8.42E-03	4.96E-03	8.30E-07	3.90E-04	1.71E-01
19	6.51E-04	7.09E-03	8.24E-03	1.81E-07	2.58E-07	1.35E-01
20	4.53E-03	4.55E-03	2.10E-02	2.17E-06	3.04E-04	1.09E-01
21	2.50E-04	4.82E-03	2.03E-02	1.91E-07	3.68E-07	9.85E-02
22	2.26E-03	2.76E-03	2.30E-02	2.51E-06	1.16E-04	7.61E-02
23	1.97E-04	3.52E-03	5.31E-03	9.84E-08	1.87E-07	7.16E-02
24	1.55E-03	1.70E-03	1.04E-02	1.21E-06	2.11E-04	5.54E-02
25	2.78E-04	2.45E-03	7.05E-03	2.85E-07	3.81E-07	5.38E-02
26	6.93E-04	1.03E-03	6.07E-03	4.42E-07	1.61E-04	4.49E-02
27	1.48E-04	1.88E-03	9.98E-03	2.53E-07	2.23E-07	4.24E-02
28	2.04E-04	6.74E-04	5.25E-03	5.06E-07	9.89E-05	3.48E-02
29	3.19E-06	1.51E-03	1.24E-02	1.23E-07	1.69E-07	3.32E-02
30	1.83E-04	4.52E-04	6.56E-03	5.36E-07	5.39E-05	2.76E-02
31	2.90E-05	1.14E-03	1.37E-02	1.61E-07	1.13E-07	2.62E-02
32	4.84E-05	3.18E-04	8.08E-03	5.83E-07	2.23E-05	2.24E-02
33	6.72E-06	9.20E-04	1.44E-02	6.11E-08	6.78E-08	2.11E-02
34	1.73E-05	2.54E-04	9.01E-03	5.72E-07	1.72E-06	1.85E-02
35	9.09E-06	7.52E-04	1.46E-02	1.41E-07	1.12E-07	1.84E-02
36	2.69E-05	2.01E-04	9.50E-03	1.16E-06	1.03E-05	1.58E-02
37	2.45E-06	6.26E-04	1.46E-02	2.04E-07	1.59E-07	1.62E-02
38	3.44E-05	1.85E-04	9.62E-03	6.55E-07	1.49E-05	1.37E-02
39	1.89E-06	5.21E-04	1.43E-02	1.18E-07	1.13E-07	1.45E-02
40	4.37E-05	1.57E-04	9.59E-03	8.31E-07	2.09E-05	1.20E-02
41	5.00E-06	4.51E-04	1.41E-02	1.98E-07	2.05E-07	1.31E-02
42	5.52E-05	1.50E-04	9.49E-03	8.61E-07	2.34E-05	1.07E-02
43	5.47E-06	3.91E-04	1.37E-02	1.23E-07	8.98E-08	1.19E-02
44	4.64E-05	1.33E-04	1.88E-02	7.74E-07	2.27E-05	9.90E-03
45	2.80E-06	3.35E-04	1.34E-02	1.05E-07	1.36E-07	1.08E-02
46	4.95E-05	1.24E-04	1.86E-02	6.52E-07	2.24E-05	9.12E-03
47	2.50E-06	2.92E-04	1.31E-02	2.46E-07	2.49E-07	9.90E-03
48	5.24E-05	1.18E-04	1.81E-02	6.75E-07	2.28E-05	8.41E-03
49	3.32E-06	2.53E-04	1.27E-02	1.22E-07	8.88E-08	9.08E-03

SWEEP NO. 50

SWEEP No. 50

ORIGINAL PAGE IS
OF POOR QUALITY

ALGEBRAIC SUM OF RESIDUAL SOURCES AT EACH LINE--RSLINE(IX,JPHI)

IX	NO. TRAVS	U	V	ENTH	FM	FUEL	PP
2	1	0.00E+00	0.00E+00	-7.01E-04	1.99E-07	4.35E-09	0.00E+00
3	1	0.00E+00	2.75E-06	-1.19E-03	-1.38E-07	7.83E-08	1.90E-04
4	1	0.00E+00	2.30E-06	-1.74E-03	1.99E-07	1.80E-06	2.30E-04
5	1	3.01E-07	1.99E-05	-4.81E-03	-7.64E-08	2.21E-05	9.91E-04
6	1	-4.65E-06	-2.47E-05	-9.05E-03	0.00E+00	9.17E-08	4.94E-03
7	2	-7.06E-06	-5.83E-06	-4.57E-05	1.53E-08	-1.53E-08	7.03E-04
8	2	4.14E-05	-2.34E-05	-3.76E-05	-8.59E-09	1.91E-08	3.09E-04
9	2	0.00E+00	-3.48E-05	-3.29E-05	0.00E+00	-2.01E-08	4.49E-04

VALUES AT MONITORING LOCATION (3, 3)

ISWEEP	U	V	ENTH	FM	FUEL	P
50	6.26E+00	-1.62E-03	-1.65E+05	3.79E-02	3.79E-02	-1.99E+01

SWEEP NO. 100

ISWEEP	H	V	ENTH	FM	FUEL	PP
50	5.34E-05	1.14E-04	1.76E-02	6.35E-07	2.42E-05	7.82E-03
51	2.20E-06	2.20E-04	1.24E-02	1.39E-07	1.15E-07	8.34E-03
52	4.48E-05	1.08E-04	1.71E-02	6.83E-07	2.32E-05	7.17E-03
53	5.04E-06	1.90E-04	1.20E-02	1.48E-07	1.22E-07	7.71E-03
54	4.66E-05	1.02E-04	1.67E-02	5.76E-07	2.26E-05	6.65E-03
55	4.44E-06	1.67E-04	1.17E-02	1.46E-07	1.75E-07	7.13E-03
56	4.54E-05	1.03E-04	1.62E-02	5.75E-07	2.19E-05	6.32E-03
57	9.91E-07	1.43E-04	1.14E-02	1.55E-07	2.03E-07	6.58E-03
58	4.66E-05	1.08E-04	1.58E-02	4.73E-07	2.15E-05	6.04E-03
59	3.14E-06	1.27E-04	1.10E-02	1.11E-07	1.86E-07	6.13E-03
60	4.77E-05	1.04E-04	1.53E-02	3.26E-07	1.98E-05	5.73E-03
61	2.80E-06	1.12E-04	1.08E-02	1.12E-07	7.26E-08	5.74E-03
62	4.34E-05	9.44E-05	1.48E-02	1.49E-06	1.83E-05	5.38E-03
63	2.53E-06	1.02E-04	1.04E-02	1.65E-07	1.77E-07	5.35E-03
64	4.20E-05	9.20E-05	1.45E-02	3.93E-07	2.16E-05	5.14E-03
65	2.45E-06	9.18E-05	1.02E-02	2.19E-07	2.06E-07	5.04E-03
66	4.01E-05	8.48E-05	1.40E-02	7.96E-07	1.99E-05	4.82E-03
67	4.69E-06	8.46E-05	9.88E-03	1.50E-07	1.18E-07	4.71E-03
68	4.33E-05	8.50E-05	1.36E-02	8.20E-07	1.92E-05	4.56E-03
69	3.19E-06	7.35E-05	9.57E-03	1.73E-07	1.76E-07	4.42E-03
70	3.78E-05	7.62E-05	1.32E-02	5.88E-07	1.74E-05	4.30E-03
71	3.23E-06	6.97E-05	9.32E-03	2.24E-07	2.31E-07	4.10E-03
72	3.43E-05	6.06E-05	1.29E-02	6.93E-07	1.87E-05	4.02E-03
73	2.71E-06	6.45E-05	9.08E-03	2.47E-07	2.03E-07	3.88E-03
74	3.65E-05	7.43E-05	1.25E-02	7.95E-07	1.68E-05	3.90E-03
75	4.91E-06	5.63E-05	8.82E-03	7.54E-08	1.04E-07	3.61E-03
76	3.60E-05	7.40E-05	1.22E-02	9.35E-07	1.70E-05	3.76E-03
77	2.37E-06	4.98E-05	8.52E-03	7.54E-08	6.88E-08	3.41E-03
78	3.46E-05	6.30E-05	1.18E-02	5.26E-07	1.49E-05	3.55E-03
79	2.28E-06	4.55E-05	8.31E-03	1.33E-07	1.77E-07	3.19E-03
80	3.64E-05	6.98E-05	1.15E-02	2.34E-07	1.57E-05	3.43E-03
81	5.34E-06	4.33E-05	8.07E-03	1.40E-07	1.16E-07	2.90E-03
82	2.88E-05	6.58E-05	1.11E-02	8.71E-07	1.49E-05	3.26E-03
83	1.64E-06	3.70E-05	7.86E-03	2.10E-07	2.17E-07	2.78E-03
84	3.44E-05	6.80E-05	1.08E-02	4.21E-07	1.52E-05	2.97E-03
85	9.91E-07	3.74E-05	7.66E-03	2.46E-07	2.66E-07	2.65E-03
86	3.05E-05	6.13E-05	1.05E-02	1.09E-06	1.57E-05	2.82E-03
87	4.91E-06	3.56E-05	7.41E-03	1.38E-07	1.66E-07	2.54E-03
88	3.34E-05	6.22E-05	1.02E-02	7.38E-07	1.30E-05	2.62E-03
89	3.27E-06	4.54E-05	1.71E-02	3.28E-07	3.31E-07	2.44E-03
90	3.33E-05	5.79E-05	9.93E-03	7.53E-07	1.34E-05	2.47E-03
91	2.89E-06	3.96E-05	1.66E-02	8.02E-08	4.68E-08	2.33E-03
92	3.24E-05	6.34E-05	9.65E-03	6.18E-07	1.26E-05	2.39E-03
93	5.68E-06	5.05E-05	2.61E-02	2.94E-07	2.97E-07	2.28E-03
94	3.80E-05	5.79E-05	1.91E-02	8.47E-07	1.41E-05	2.26E-03
95	4.91E-06	4.83E-05	2.54E-02	2.65E-07	2.54E-07	2.20E-03
96	2.90E-05	5.22E-05	1.87E-02	1.03E-06	1.02E-05	2.09E-03
97	3.57E-06	4.71E-05	2.47E-02	2.09E-07	1.73E-07	2.11E-03
98	2.86E-05	4.62E-05	2.78E-02	8.42E-07	1.11E-05	1.91E-03
99	3.92E-06	4.71E-05	2.30E-02	2.24E-07	1.71E-07	2.04E-03

SWEEP NO. 100

SWEEP NO. 100

ORIGINAL PAGE IS
OF POOR QUALITY

ALGEBRAIC SUM OF RESIDUAL SOURCES AT EACH LINE BASELINE (IX, JPHI)

IX	NO. TRAVS	U	V	ENTH	FM	FUEL	PP
2	1	-6.89E-07	0.00E+00	-3.47E-04	-1.53E-08	2.17E-03	0.00E+00
3	1	0.00E+00	1.63E-06	-5.81E-04	4.58E-08	3.86E-08	4.95E-05
4	1	-1.38E-06	4.02E-06	-8.49E-04	-2.60E-07	8.54E-07	7.19E-05
5	1	6.89E-07	3.99E-06	-2.34E-03	-7.64E-08	1.06E-05	2.31E-04
6	1	-4.74E-07	-1.59E-06	-4.42E-03	4.58E-08	3.06E-08	8.64E-04
7	1	-1.65E-06	6.86E-06	-9.07E-03	3.06E-08	1.53E-08	2.53E-04
8	1	1.92E-05	-1.02E-05	-9.49E-03	-2.48E-08	-3.25E-08	2.29E-04
9	2	0.00E+00	-1.55E-05	-1.69E-05	-1.62E-08	2.77E-08	1.35E-04

VALUES AT MONITORING LOCATION (3, 3)

ISWLEP	U	V	ENTH	FM	FUEL	P
100	6.26E+00	-1.62E-03	-1.65E+05	3.79E-02	3.79E-02	-1.99E+01

SWEEP NO. 150

ISXLEP	H	V	LGTH	FM	FUEL	PP
100	2.40E-05	4.30E-05	2.71E-02	5.15E-07	1.17E-05	1.83E-03
101	4.01E-06	4.42E-05	2.33E-02	1.62E-07	1.41E-07	1.98E-03
102	2.37E-05	5.42E-05	2.63E-02	8.89E-07	1.11E-05	1.90E-03
103	4.14E-06	4.68E-05	2.27E-02	4.26E-07	3.46E-07	1.97E-03
104	2.31E-05	5.86E-05	2.56E-02	9.69E-07	1.24E-05	1.91E-03
105	4.26E-06	4.94E-05	2.20E-02	1.24E-07	1.34E-07	1.92E-03
106	1.84E-05	5.25E-05	2.49E-02	4.54E-07	1.06E-05	1.81E-03
107	5.08E-06	4.84E-05	2.14E-02	1.59E-07	2.08E-07	1.87E-03
108	2.57E-05	4.86E-05	2.42E-02	8.01E-07	1.03E-05	1.71E-03
109	4.65E-06	4.96E-05	2.08E-02	1.96E-07	2.54E-07	1.82E-03
110	2.45E-05	5.36E-05	2.35E-02	4.01E-07	1.03E-05	1.70E-03
111	4.13E-06	4.75E-05	2.02E-02	2.36E-07	1.54E-07	1.78E-03
112	2.34E-05	5.47E-05	2.28E-02	5.38E-07	9.16E-06	1.67E-03
113	2.15E-06	4.94E-05	1.96E-02	1.52E-07	1.55E-07	1.75E-03
114	2.54E-05	5.16E-05	2.21E-02	8.40E-07	9.76E-06	1.62E-03
115	3.45E-06	4.63E-05	1.91E-02	2.01E-07	1.65E-07	1.69E-03
116	2.08E-05	5.30E-05	2.15E-02	3.63E-07	9.26E-06	1.59E-03
117	3.23E-06	4.63E-05	1.85E-02	3.24E-07	2.78E-07	1.65E-03
118	1.55E-05	5.23E-05	2.09E-02	4.83E-07	8.91E-06	1.52E-03
119	4.87E-06	4.41E-05	1.79E-02	1.47E-07	1.31E-07	1.61E-03
120	1.87E-05	5.98E-05	2.03E-02	6.01E-07	9.52E-06	1.54E-03
121	5.51E-06	4.76E-05	1.75E-02	1.11E-07	1.68E-07	1.60E-03
122	2.03E-05	5.69E-05	1.97E-02	5.62E-07	9.17E-06	1.53E-03
123	2.67E-06	4.46E-05	1.70E-02	1.47E-07	9.65E-06	1.56E-03
124	1.85E-05	4.63E-05	1.91E-02	6.76E-07	9.01E-06	1.37E-03
125	2.58E-06	4.52E-05	1.65E-02	1.30E-07	1.44E-07	1.53E-03
126	1.78E-05	4.63E-05	1.86E-02	1.06E-06	6.91E-06	1.35E-03
127	5.38E-06	4.04E-05	1.60E-02	2.23E-07	2.44E-07	1.48E-03
128	1.71E-05	4.65E-05	1.80E-02	5.76E-07	9.54E-06	1.34E-03
129	3.32E-06	4.08E-05	1.55E-02	3.37E-07	2.76E-07	1.45E-03
130	1.79E-05	4.71E-05	1.75E-02	7.53E-07	7.17E-06	1.21E-03
131	3.92E-06	4.16E-05	1.51E-02	3.89E-07	2.71E-07	1.42E-03
132	2.27E-05	3.97E-05	1.70E-02	9.38E-07	6.78E-06	1.14E-03
133	5.21E-06	4.05E-05	1.46E-02	1.75E-07	1.88E-07	1.35E-03
134	1.65E-05	3.40E-05	1.65E-02	5.60E-07	7.13E-06	1.10E-03
135	3.92E-06	3.56E-05	1.42E-02	9.07E-08	1.99E-07	1.29E-03
136	1.56E-05	3.39E-05	1.60E-02	6.47E-07	6.85E-06	1.09E-03
137	3.66E-06	3.55E-05	1.38E-02	3.43E-07	2.93E-07	1.28E-03
138	1.51E-05	3.49E-05	1.56E-02	7.02E-07	7.58E-06	1.03E-03
139	3.92E-06	3.25E-05	1.34E-02	1.00E-07	9.74E-08	1.25E-03
140	1.72E-05	3.92E-05	1.51E-02	4.18E-07	6.27E-06	1.06E-03
141	5.08E-06	3.34E-05	1.30E-02	3.85E-07	1.97E-07	1.19E-03
142	1.63E-05	3.69E-05	1.47E-02	3.33E-07	6.08E-06	1.03E-03
143	4.22E-06	3.34E-05	2.26E-02	2.10E-07	2.21E-07	1.16E-03
144	4.82E-06	2.20E-05	2.42E-02	9.81E-07	7.14E-06	9.67E-04
145	4.31E-06	2.81E-05	2.20E-02	1.37E-07	1.61E-07	1.10E-03
146	4.35E-06	2.84E-05	2.35E-02	7.10E-07	4.94E-06	9.91E-04
147	4.65E-06	2.86E-05	2.14E-02	1.04E-07	6.97E-08	1.10E-03
148	3.23E-05	2.72E-05	2.29E-02	5.06E-07	6.80E-06	9.36E-04
149	5.25E-06	2.86E-05	2.07E-02	2.75E-07	2.81E-07	1.10E-03

SWEEP NO. 150

SWEEP No. 150

ORIGINAL PAGE IS
OF POOR QUALITY

ALGEBRAIC SUM OF RESIDUAL SOURCES AT EACH LINE--RSLINE(IX,JPHI)

IX	NO. TRAVS	U	V	ENTH	FM	FUEL	PP
2	1	-6.89E-07	0.00E+00	-1.65E-04	-1.07E-07	7.48E-10	0.00E+00
3	1	-6.89E-07	-6.26E-06	-2.75E-04	-2.44E-07	1.45E-08	6.47E-05
4	1	0.00E+00	2.07E-06	-4.13E-04	3.21E-07	3.55E-07	6.56E-05
5	1	-2.15E-07	-1.42E-06	-1.13E-03	3.06E-08	4.76E-06	2.65E-05
6	1	-5.17E-07	6.20E-07	-2.13E-03	0.00E+00	4.58E-08	2.16E-04
7	1	-1.46E-06	5.51E-06	-4.36E-03	0.00E+00	4.58E-08	2.99E-04
8	1	1.21E-06	-1.19E-05	-4.58E-03	1.15E-08	1.53E-08	1.81E-04
9	1	0.00E+00	-5.93E-06	-9.15E-03	3.25E-08	1.24E-08	1.06E-04

VALUES AT MONITORING LOCATION (3, 3)

ISWEEP	U	V	ENTH	FM	FUEL	P
150	6.26E+00	-1.63E-03	-1.65E+05	3.79E-02	3.79E-02	-1.99E+01

SUM OF ABS. VALUES OF RSLINE(IX,JPHI)-

ISWEEP	U	V	ENTH	FM	FUEL	PP
150	4.77E-06	3.37E-05	2.22E-02	7.47E-07	5.25E-06	9.59E-04

FIELD VALUES OF

	U	U	U	U	U	U	U	U	U	U
Y(10)=9.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(9)=8.000E-03	-4.51E+00	-4.51E+00	-4.62E+00	-4.59E+00	-1.12E+03	-1.07E+00	-1.56E+00	-2.23E+00	0.00E+00	0.00E+00
Y(8)=6.750E-03	-4.51E+00	-4.51E+00	-4.62E+00	-4.60E+00	-1.10E+03	-9.28E-01	-8.85E-01	-9.75E-01	0.00E+00	0.00E+00
Y(7)=4.750E-03	-4.35E+00	-4.35E+00	-4.45E+00	-4.44E+00	-1.05E+03	-6.96E-01	-9.04E-02	9.14E-01	0.00E+00	0.00E+00
Y(6)=3.750E-03	-4.17E+00	-4.17E+00	-4.24E+00	-4.22E+00	-1.01E+03	-6.27E-01	9.10E-02	2.33E+00	0.00E+00	0.00E+00
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.33E-17	3.27E+00	0.00E+00	0.00E+00
Y(4)=2.750E-03	5.68E+00	5.67E+00	5.97E+00	6.29E+00	6.49E+00	6.52E+00	6.56E+00	4.24E+00	0.00E+00	0.00E+00
Y(3)=1.500E-03	5.68E+00	5.89E+00	6.26E+00	6.64E+00	6.75E+00	6.80E+00	6.80E+00	4.99E+00	0.00E+00	0.00E+00
Y(2)=5.000E-04	3.18E+00	5.93E+00	6.36E+00	6.77E+00	6.86E+00	6.91E+00	6.89E+00	5.20E+00	0.00E+00	0.00E+00
Y(1)=0.000E+00	3.18E+00	5.93E+00	6.36E+00	6.77E+00	6.86E+00	6.91E+00	6.89E+00	5.20E+00	0.00E+00	0.00E+00

XU(IX) 1= 0.000 2= 0.050 3= 0.095 4= 0.145 5= 0.179 6= 0.192 7= 0.200 8= 0.205 9= 0.210

FIELD VALUES OF

	V	V	V	V	V	V	V	V	V	V	V
Y(9)=9.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(8)=7.375E-03	0.00E+00	-4.98E-24	-1.50E-04	1.17E-04	-4.18E-03	-2.15E-02	-1.24E-01	-2.47E-01	8.03E-01	0.00E+00	0.00E+00
Y(7)=5.750E-03	0.00E+00	-6.53E-24	-4.09E-04	-1.14E-05	-5.34E-03	-2.87E-02	-1.52E-01	-3.52E-01	1.39E+00	0.00E+00	0.00E+00
Y(6)=4.250E-03	0.00E+00	-2.86E-24	-3.23E-04	-1.95E-04	-1.37E-03	-1.24E-02	-6.54E-02	-1.20E-01	1.55E+00	0.00E+00	0.00E+00
Y(5)=3.500E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.27E-01	1.50E+00	0.00E+00	0.00E+00
Y(4)=3.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.17E-01	1.39E+00	0.00E+00	0.00E+00
Y(3)=2.125E-03	0.00E+00	-1.29E-02	-1.63E-03	-5.28E-04	2.16E-03	1.77E-07	4.34E-03	3.81E-01	1.07E+00	0.00E+00	0.00E+00
Y(2)=1.000E-03	0.00E+00	-3.89E-02	-2.44E-03	-4.82E-04	1.47E-03	1.57E-04	3.11E-03	1.70E-01	5.21E-01	0.00E+00	0.00E+00
Y(1)=0.000E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

X(IX) 1= 0.000 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207 10= 0.210

FIELD VALUES IN ENTH

	-----LUTH-----									
Y(10)=9.000E-03	6.38E+02	6.38E+02	7.38E+02	7.63E+02	6.06E+02	6.45E+02	6.29E+02	6.23E+02	6.20E+02	6.19E+02
Y(9)=8.000E-03	-3.36E+05	-3.36E+05	-2.79E+05	-2.13E+05	-1.48E+05	-1.19E+05	-1.20E+05	-1.23E+05	-1.25E+05	6.18E+02
Y(8)=6.750E-03	-3.33E+05	-3.33E+05	-2.67E+05	-2.10E+05	-1.47E+05	-1.20E+05	-1.21E+05	-1.24E+05	-1.26E+05	6.18E+02
Y(7)=4.750E-03	-3.33E+05	-3.33E+05	-2.68E+05	-2.10E+05	-1.47E+05	-1.20E+05	-1.21E+05	-1.24E+05	-1.26E+05	6.18E+02
Y(6)=3.750E-03	-3.35E+05	-3.35E+05	-2.71E+05	-2.13E+05	-1.49E+05	-1.20E+05	-1.21E+05	-1.25E+05	-1.27E+05	6.18E+02
Y(5)=3.250E-03	4.19E+02	4.89E+02	5.11E+02	5.21E+02	4.54E+02	4.12E+02	4.04E+02	-1.26E+05	-1.28E+05	6.18E+02
Y(4)=2.750E-03	-2.34E+04	-1.42E+05	-1.52E+05	-1.57E+05	-1.31E+05	-1.29E+05	-1.28E+05	-1.28E+05	-1.28E+05	6.18E+02
Y(3)=1.500E-03	-2.34E+04	-1.84E+05	-1.65E+05	-1.43E+05	-1.34E+05	-1.32E+05	-1.30E+05	-1.30E+05	-1.29E+05	6.17E+02
Y(2)=5.000E-04	-4.72E+06	-3.17E+05	-1.80E+05	-1.47E+05	-1.36E+05	-1.33E+05	-1.31E+05	-1.31E+05	-1.30E+05	6.17E+02
Y(1)=0.000E+00	-4.72E+06	-3.17E+05	-1.80E+05	-1.47E+05	-1.36E+05	-1.33E+05	-1.31E+05	-1.31E+05	-1.30E+05	6.17E+02
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF FM

	-----FM-----									
Y(10)=9.000E-03	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02
Y(9)=8.000E-03	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02
Y(8)=6.750E-03	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02
Y(7)=4.750E-03	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.71E-02	3.71E-02	3.72E-02
Y(6)=3.750E-03	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.71E-02	3.70E-02	3.72E-02
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.70E-02	3.72E-02
Y(4)=2.750E-03	0.00E+00	3.01E-02	3.62E-02	3.73E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.72E-02	3.72E-02
Y(3)=1.500E-03	0.00E+00	3.02E-02	3.79E-02	3.75E-02	3.75E-02	3.74E-02	3.74E-02	3.74E-02	3.73E-02	3.73E-02
Y(2)=5.000E-04	1.00E+00	6.65E-02	4.07E-02	3.78E-02	3.75E-02	3.75E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02
Y(1)=0.000E+00	1.00E+00	6.65E-02	4.07E-02	3.78E-02	3.75E-02	3.75E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF FUEL

	-----FUEL-----									
Y(10)=9.000E-03	9.13E-08	9.13E-08	1.85E-06	4.55E-05	1.56E-03	3.57E-02	3.71E-02	3.71E-02	3.72E-02	3.72E-02
Y(9)=8.000E-03	9.13E-08	9.13E-08	1.85E-06	4.55E-05	1.56E-03	3.57E-02	3.71E-02	3.71E-02	3.72E-02	3.72E-02
Y(8)=6.750E-03	8.89E-08	8.89E-08	1.80E-06	4.44E-05	1.52E-03	3.56E-02	3.70E-02	3.71E-02	3.72E-02	3.72E-02
Y(7)=4.750E-03	8.28E-08	8.28E-08	1.67E-06	4.13E-05	1.44E-03	3.55E-02	3.70E-02	3.71E-02	3.72E-02	3.72E-02
Y(6)=3.750E-03	8.11E-08	8.11E-08	1.63E-06	4.02E-05	1.41E-03	3.55E-02	3.70E-02	3.70E-02	3.72E-02	3.72E-02
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.70E-02	3.72E-02
Y(4)=2.750E-03	0.00E+00	3.01E-02	3.62E-02	3.73E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.72E-02	3.72E-02
Y(3)=1.500E-03	0.00E+00	3.82E-02	3.79E-02	3.75E-02	3.75E-02	3.74E-02	3.74E-02	3.74E-02	3.73E-02	3.73E-02
Y(2)=5.000E-04	1.00E+00	6.65E-02	4.07E-02	3.78E-02	3.75E-02	3.75E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02
Y(1)=0.000E+00	1.00E+00	6.65E-02	4.07E-02	3.78E-02	3.75E-02	3.75E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FILLO VALUES OF	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10
Y(10)=9.000L-03	9.45E-15	9.45E-15	2.91E-14	7.25E-14	5.18E-14	2.28E-15	1.49E-16	2.52E-17	1.57E-17	1.57E-17
Y(9)=0.000E-03	9.45E-15	9.45E-15	2.91E-14	7.25E-14	5.18E-14	2.28E-15	1.49E-16	2.52E-17	1.57E-17	1.57E-17
Y(8)=6.750L-03	9.97E-15	9.97E-15	3.05E-14	7.59E-14	5.49E-14	2.37E-15	1.74E-16	2.86E-17	1.53E-17	1.53E-17
Y(7)=4.750L-03	9.97E-15	9.97E-15	3.04E-14	7.58E-14	5.90E-14	2.56E-15	2.31E-16	3.23E-17	1.48E-17	1.48E-17
Y(6)=3.750L-03	9.40E-15	9.40E-15	2.99E-14	7.23E-14	5.86E-14	2.60E-15	2.47E-16	2.47E-17	1.18E-17	1.18E-17
Y(5)=3.250L-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-17	9.12E-18	9.12E-18
Y(4)=2.750L-03	0.00E+00	6.41E-32	2.55E-29	1.24E-26	6.07E-24	1.11E-21	1.24E-19	7.38E-18	6.78E-18	6.78E-18
Y(3)=1.500L-03	0.00E+00	6.49E-32	2.52E-29	1.22E-26	5.80E-24	9.15E-22	7.31E-20	2.23E-18	3.60E-18	3.60E-18
Y(2)=0.000E-04	0.00E+00	6.83E-32	2.51E-29	1.21E-26	5.63E-24	8.10E-22	5.28E-20	1.15E-18	2.54E-18	2.54E-18
Y(1)=0.000L+00	0.00E+00	6.83E-32	2.51E-29	1.21E-26	5.63E-24	8.10E-22	5.28E-20	1.15E-18	2.54E-18	2.54E-18
X(1X)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF	NO									
Y(10)=9.000E-03	4.18E-06	4.18E-06	4.83E-06	4.38E-06	1.82E-06	7.70E-08	4.95E-09	8.24E-10	5.08E-1n	5.08E-1U
Y(9)=8.000E-03	4.18E-06	4.18E-06	4.83E-06	4.38E-06	1.82E-06	7.70E-08	4.95E-09	8.24E-10	5.08E-1n	5.08E-1U
Y(8)=6.750E-05	4.13E-06	4.13E-06	4.81E-06	4.39E-06	1.85E-06	7.94E-08	5.75E-09	9.32E-10	4.96E-1n	4.96E-1U
Y(7)=4.750E-03	4.06E-06	4.06E-06	4.79E-06	4.44E-06	1.93E-06	8.51E-08	7.61E-09	1.05E-09	4.79E-1n	4.79E-1U
Y(6)=3.750E-03	4.01E-06	4.01E-06	4.77E-06	4.45E-06	1.96E-06	8.64E-08	8.11E-09	8.03E-10	3.81E-1n	3.81E-1U
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.88E-10	2.94E-1n	2.94E-1U
Y(4)=2.750E-03	0.00E+00	1.71E-24	7.24E-22	3.69E-19	1.89E-16	3.52E-14	4.00E-12	2.39E-10	2.18E-1n	2.18E-1U
Y(3)=1.500E-03	0.00E+00	1.70E-24	7.10E-22	3.60E-19	1.79E-16	2.89E-14	2.34E-12	7.18E-11	1.16E-1n	1.16E-1U
Y(2)=5.000E-04	0.00E+00	1.77E-24	7.00E-22	3.54E-19	1.73E-16	2.55E-14	1.68E-12	3.69E-11	8.13E-1n	8.13E-1U
Y(1)=0.000E+00	0.00E+00	1.77E-24	7.00E-22	3.54E-19	1.73E-16	2.55E-14	1.68E-12	3.69E-11	8.13E-1n	8.13E-1U
X(1X)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF		H02									
Y (1)=2.000E-03	2.58E-08	2.58E-08	2.56E-08	2.05E-08	9.48E-09	3.99E-10	2.56E-11	4.26E-12	2.63E-12	2.63E-12	
Y (9)=8.000E-03	2.50E-08	2.58E-08	2.56E-08	2.05E-08	9.48E-09	3.99E-10	2.56E-11	4.26E-12	2.63E-12	2.63E-12	
Y (8)=6.750E-03	2.52E-08	2.52E-08	2.53E-08	2.05E-08	9.55E-09	4.11E-10	2.97E-11	4.82E-12	2.57E-12	2.57E-12	
Y (7)=4.750E-03	2.48E-08	2.48E-08	2.52E-08	2.07E-08	9.84E-09	4.39E-10	3.93E-11	5.45E-12	2.48E-12	2.48E-12	
Y (6)=3.750E-03	2.47E-08	2.47E-08	2.52E-08	2.09E-08	1.00E-08	4.45E-10	4.19E-11	4.15E-12	1.97E-12	1.97E-12	
Y (5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.52E-12	1.52E-12	1.52E-12	
Y (4)=2.750E-03	0.00E+00	8.85E-27	3.75E-24	1.91E-21	9.77E-19	1.82E-16	2.07E-14	1.24E-12	1.13E-12	1.13E-12	
Y (3)=1.500E-03	0.00E+00	8.85E-27	3.68E-24	1.87E-21	9.27E-19	1.50E-16	1.21E-14	3.71E-13	5.98E-13	5.98E-13	
Y (2)=5.000E-04	0.00E+00	9.19E-27	3.62E-24	1.83E-21	8.94E-19	1.32E-16	8.69E-15	1.91E-13	4.20E-13	4.20E-13	
Y (1)=0.000E+00	0.00E+00	9.19E-27	3.62E-24	1.83E-21	8.94E-19	1.32E-16	8.69E-15	1.91E-13	4.20E-13	4.20E-13	
X(1X)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210	

FIELD VALUES OF H2O		H2O									
Y(10)=9.000E-03	4.44E-09	6.44E-09	8.13E-09	1.01E-08	9.18E-09	3.91E-10	2.54E-11	4.31E-12	2.68E-12	2.68E-12	
Y(9)=8.000E-03	6.44E-09	6.44E-09	8.13E-09	1.01E-08	9.18E-09	3.91E-10	2.54E-11	4.31E-12	2.68E-12	2.68E-12	
Y(8)=6.750E-03	6.51E-09	6.51E-09	8.22E-09	1.02E-08	9.31E-09	4.05E-10	2.96E-11	4.87E-12	2.62E-12	2.62E-12	
Y(7)=4.750E-03	6.51E-09	6.51E-09	8.21E-09	1.02E-08	9.49E-09	4.31E-10	3.92E-11	5.51E-12	2.52E-12	2.52E-12	
Y(6)=3.750E-03	6.45E-09	6.45E-09	8.12E-09	1.01E-08	9.47E-09	4.37E-10	4.19E-11	4.21E-12	2.02E-12	2.02E-12	
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.56E-12	1.56E-12	1.56E-12	
Y(4)=2.750E-03	0.00E+00	1.11E-26	4.40E-24	2.13E-21	1.04E-18	1.69E-16	2.12E-14	1.26E-12	1.16E-12	1.16E-12	
Y(3)=1.500E-03	0.00E+00	1.12E-26	4.36E-24	2.10E-21	9.95E-19	1.57E-16	1.25E-14	3.80E-13	6.15E-13	6.15E-13	
Y(2)=5.000E-04	0.00E+00	1.19E-26	4.35E-24	2.08E-21	9.66E-19	1.39E-16	9.03E-15	1.96E-13	4.33E-13	4.33E-13	
Y(1)=0.000E+00	0.00E+00	1.19E-26	4.35E-24	2.08E-21	9.66E-19	1.39E-16	9.03E-15	1.96E-13	4.33E-13	4.33E-13	
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210	

FIELD VALUES OF H2		H2									
Y(10)=9.000E-03	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	
Y(9)=8.000E-03	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	
Y(8)=6.750E-03	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	
Y(7)=4.750E-03	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	
Y(6)=3.750E-03	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.40E-01	7.39E-01	
Y(4)=2.750E-03	7.68E-01	7.45E-01	7.40E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	
Y(3)=1.500E-03	7.60E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	
Y(2)=5.000E-04	0.00E+00	7.17E-01	7.37E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	
Y(1)=0.000E+00	0.00E+00	7.17E-01	7.37E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210	

FIELD VALUES OF F		F									
Y(10)=9.000E-03	9.13E-08	9.13E-08	1.85E-06	4.55E-05	1.56E-03	3.57E-02	3.71E-02	3.71E-02	3.72E-02	3.72E-02	
Y(9)=8.000E-03	9.13E-08	9.13E-08	1.85E-06	4.55E-05	1.56E-03	3.57E-02	3.71E-02	3.71E-02	3.72E-02	3.72E-02	
Y(8)=6.750E-03	8.89E-08	8.89E-08	1.80E-06	4.44E-05	1.52E-03	3.56E-02	3.70E-02	3.71E-02	3.72E-02	3.72E-02	
Y(7)=4.750E-03	8.28E-08	8.28E-08	1.67E-06	4.13E-05	1.44E-03	3.55E-02	3.70E-02	3.71E-02	3.72E-02	3.72E-02	
Y(6)=3.750E-03	8.11E-08	8.11E-08	1.63E-06	4.02E-05	1.41E-03	3.55E-02	3.70E-02	3.70E-02	3.72E-02	3.72E-02	
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.70E-02	3.72E-02	
Y(4)=2.750E-03	0.00E+00	3.01E-02	3.62E-02	3.73E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.72E-02	3.72E-02	
Y(3)=1.500E-03	0.00E+00	3.02E-02	3.79E-02	3.75E-02	3.75E-02	3.74E-02	3.74E-02	3.74E-02	3.73E-02	3.73E-02	
Y(2)=5.000E-04	1.00E+00	6.65E-02	4.07E-02	3.78E-02	3.75E-02	3.75E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	
Y(1)=0.000E+00	1.00E+00	6.65E-02	4.07E-02	3.78E-02	3.75E-02	3.75E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210	

ORIGINAL PAGE IS
OF POOR QUALITY

FIELD VALUES OF C0

Y(10)=9.800E-03	7.48E-02	7.48E-02	7.48E-02	7.49E-02	8.10E-02	2.17E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01
Y(9)=8.000E-03	7.48E-02	7.48E-02	7.48E-02	7.49E-02	8.10E-02	2.17E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01
Y(8)=6.750E-03	7.48E-02	7.48E-02	7.48E-02	7.49E-02	8.09E-02	2.17E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01
Y(7)=4.750E-03	7.48E-02	7.48E-02	7.48E-02	7.49E-02	8.05E-02	2.17E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01
Y(6)=3.750E-03	7.48E-02	7.48E-02	7.48E-02	7.49E-02	8.04E-02	2.17E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(4)=2.750E-03	2.32E-01	2.25E-01	2.24E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01
Y(3)=1.500E-03	2.32E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01
Y(2)=5.000E-04	0.00E+00	2.17E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01
Y(1)=0.000E+00	0.00E+00	2.17E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01

X(IX) 1= 0.000 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207 10= 0.210

FIELD VALUES OF C0

Y(10)=9.000E-03	1.13E-05	1.13E-05	1.62E-05	2.20E-05	1.97E-05	4.38E-12	2.85E-13	4.82E-14	2.99E-14	2.99E-14	2.99E-14
Y(9)=8.000E-03	1.13E-05	1.13E-05	1.62E-05	2.20E-05	1.97E-05	4.38E-12	2.85E-13	4.82E-14	2.99E-14	2.99E-14	2.99E-14
Y(8)=6.750E-03	1.15E-05	1.15E-05	1.65E-05	2.24E-05	2.01E-05	4.51E-12	3.32E-13	5.45E-14	2.92E-14	2.92E-14	2.92E-14
Y(7)=4.750E-03	1.15E-05	1.15E-05	1.65E-05	2.24E-05	2.06E-05	4.81E-12	4.39E-13	6.17E-14	2.82E-14	2.82E-14	2.82E-14
Y(6)=3.750E-03	1.13E-05	1.13E-05	1.62E-05	2.20E-05	2.05E-05	4.88E-12	4.69E-13	4.70E-14	2.25E-14	2.25E-14	2.25E-14
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.86E-14	1.74E-14	1.74E-14
Y(4)=2.750E-03	0.00E+00	5.85E-20	5.85E-20	5.85E-20	5.85E-20	5.85E-20	1.96E-16	1.40E-14	1.29E-14	1.29E-14	1.29E-14
Y(3)=1.500E-03	0.00E+00	5.85E-20	5.85E-20	5.85E-20	5.85E-20	5.85E-20	1.20E-16	4.24E-15	6.81E-15	6.81E-15	6.81E-15
Y(2)=5.000E-04	0.00E+00	5.85E-20	5.85E-20	5.85E-20	5.85E-20	5.85E-20	7.62E-17	2.17E-15	4.79E-15	4.79E-15	4.79E-15
Y(1)=0.000E+00	0.00E+00	5.85E-20	5.85E-20	5.85E-20	5.85E-20	5.85E-20	7.62E-17	2.17E-15	4.79E-15	4.79E-15	4.79E-15

X(IX) 1= 0.000 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207 10= 0.210

FIELD VALUES OF C02

Y(10)=9.000E-03	1.02E-01	1.02E-01	1.02E-01	1.02E-01	9.78E-02	4.12E-03	2.68E-04	4.53E-05	2.81E-05	2.81E-05	2.81E-05
Y(9)=8.000E-03	1.02E-01	1.02E-01	1.02E-01	1.02E-01	9.78E-02	4.12E-03	2.68E-04	4.53E-05	2.81E-05	2.81E-05	2.81E-05
Y(8)=6.750E-03	1.02E-01	1.02E-01	1.02E-01	1.02E-01	9.79E-02	4.25E-03	3.12E-04	5.13E-05	2.75E-05	2.75E-05	2.75E-05
Y(7)=4.750E-03	1.02E-01	1.02E-01	1.02E-01	1.02E-01	9.81E-02	4.52E-03	4.13E-04	5.80E-05	2.65E-05	2.65E-05	2.65E-05
Y(6)=3.750E-03	1.02E-01	1.02E-01	1.02E-01	1.02E-01	9.82E-02	4.59E-03	4.41E-04	4.42E-05	2.12E-05	2.12E-05	2.12E-05
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.69E-05	1.63E-05	1.63E-05	1.63E-05
Y(4)=2.750E-03	0.00E+00	5.50E-11	5.50E-11	5.50E-11	5.50E-11	5.50E-11	1.84E-07	1.32E-05	1.21E-05	1.21E-05	1.21E-05
Y(3)=1.500E-03	0.00E+00	5.50E-11	5.50E-11	5.50E-11	5.50E-11	5.50E-11	1.13E-07	3.98E-06	6.40E-06	6.40E-06	6.40E-06
Y(2)=5.000E-04	0.00E+00	5.50E-11	5.50E-11	5.50E-11	5.50E-11	5.50E-11	7.17E-08	2.04E-06	4.51E-06	4.51E-06	4.51E-06
Y(1)=0.000E+00	0.00E+00	5.50E-11	5.50E-11	5.50E-11	5.50E-11	5.50E-11	7.17E-08	2.04E-06	4.51E-06	4.51E-06	4.51E-06

X(IX) 1= 0.000 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207 10= 0.210

FIELD VALUES OF H1	H1	H1	H1	H1	H1	H1	H1	H1	H1	H1	H1	H1	H1	H1	H1	H1	H1	H1	H1	H1
Y(10)=9.000E-03	1.92E-09	1.92E-09	3.33E-09	5.29E-09	4.55E-09	3.65E-18	2.37E-19	4.01E-20	2.49E-20	2.49E-20	2.49E-20	2.49E-20	2.49E-20	2.49E-20	2.49E-20	2.49E-20	2.49E-20	2.49E-20	2.49E-20	2.49E-20
Y(9)=8.000E-03	1.92E-09	1.92E-09	3.33E-09	5.29E-09	4.55E-09	3.65E-18	2.37E-19	4.01E-20	2.49E-20	2.49E-20	2.49E-20	2.49E-20	2.49E-20	2.49E-20	2.49E-20	2.49E-20	2.49E-20	2.49E-20	2.49E-20	2.49E-20
Y(8)=6.750E-03	1.97E-09	1.97E-09	3.41E-09	5.41E-09	4.68E-09	3.75E-18	2.76E-19	4.53E-20	2.43E-20	2.43E-20	2.43E-20	2.43E-20	2.43E-20	2.43E-20	2.43E-20	2.43E-20	2.43E-20	2.43E-20	2.43E-20	2.43E-20
Y(7)=4.750E-03	1.97E-09	1.97E-09	3.40E-09	5.41E-09	4.85E-09	4.00E-18	3.65E-19	5.13E-20	2.35E-20	2.35E-20	2.35E-20	2.35E-20	2.35E-20	2.35E-20	2.35E-20	2.35E-20	2.35E-20	2.35E-20	2.35E-20	2.35E-20
Y(6)=3.750E-03	1.92E-09	1.92E-09	3.32E-09	5.20E-09	4.83E-09	4.06E-18	3.90E-19	3.91E-20	1.87E-20	1.87E-20	1.87E-20	1.87E-20	1.87E-20	1.87E-20	1.87E-20	1.87E-20	1.87E-20	1.87E-20	1.87E-20	1.87E-20
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.38E-20	1.44E-20	1.44E-20	1.44E-20	1.44E-20	1.44E-20	1.44E-20	1.44E-20	1.44E-20	1.44E-20	1.44E-20	1.44E-20
Y(4)=2.750E-03	0.00E+00	4.86E-26	4.86E-26	4.86E-26	4.86E-26	4.86E-26	1.63E-22	1.17E-20	1.07E-20	1.07E-20	1.07E-20	1.07E-20	1.07E-20	1.07E-20	1.07E-20	1.07E-20	1.07E-20	1.07E-20	1.07E-20	1.07E-20
Y(3)=1.500E-03	0.00E+00	4.86E-26	4.86E-26	4.86E-26	4.86E-26	4.86E-26	9.96E-23	3.52E-21	5.66E-21	5.66E-21	5.66E-21	5.66E-21	5.66E-21	5.66E-21	5.66E-21	5.66E-21	5.66E-21	5.66E-21	5.66E-21	5.66E-21
Y(2)=5.000E-04	0.00E+00	4.86E-26	4.86E-26	4.86E-26	4.86E-26	4.86E-26	6.34E-23	1.80E-21	3.98E-21	3.98E-21	3.98E-21	3.98E-21	3.98E-21	3.98E-21	3.98E-21	3.98E-21	3.98E-21	3.98E-21	3.98E-21	3.98E-21
Y(1)=0.300E+00	0.00E+00	4.86E-26	4.86E-26	4.86E-26	4.86E-26	4.86E-26	6.34E-23	1.80E-21	3.98E-21	3.98E-21	3.98E-21	3.98E-21	3.98E-21	3.98E-21	3.98E-21	3.98E-21	3.98E-21	3.98E-21	3.98E-21	3.98E-21

X(IX) 1= 0.000 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207 10= 0.210

FIELD VALUES OF H2	H2	H2	H2	H2	H2	H2	H2	H2	H2	H2	H2	H2	H2	H2	H2	H2	H2	H2	H2	H2
Y(10)=9.000E-03	5.42E-07	5.42E-07	7.43E-07	9.69E-07	8.73E-07	1.20E-12	7.77E-14	1.31E-14	8.15E-15	8.15E-15	8.15E-15	8.15E-15	8.15E-15	8.15E-15	8.15E-15	8.15E-15	8.15E-15	8.15E-15	8.15E-15	8.15E-15
Y(9)=8.000E-03	5.42E-07	5.42E-07	7.43E-07	9.69E-07	8.73E-07	1.20E-12	7.77E-14	1.31E-14	8.15E-15	8.15E-15	8.15E-15	8.15E-15	8.15E-15	8.15E-15	8.15E-15	8.15E-15	8.15E-15	8.15E-15	8.15E-15	8.15E-15
Y(8)=6.750E-03	5.51E-07	5.51E-07	7.53E-07	9.82E-07	8.80E-07	1.23E-12	9.04E-14	1.49E-14	7.96E-15	7.96E-15	7.96E-15	7.96E-15	7.96E-15	7.96E-15	7.96E-15	7.96E-15	7.96E-15	7.96E-15	7.96E-15	7.96E-15
Y(7)=4.750E-03	5.51E-07	5.51E-07	7.52E-07	9.81E-07	9.07E-07	1.31E-12	1.20E-13	1.68E-14	7.69E-15	7.69E-15	7.69E-15	7.69E-15	7.69E-15	7.69E-15	7.69E-15	7.69E-15	7.69E-15	7.69E-15	7.69E-15	7.69E-15
Y(6)=3.750E-03	5.43E-07	5.43E-07	7.42E-07	9.68E-07	9.05E-07	1.33E-12	1.28E-13	1.28E-14	6.13E-15	6.13E-15	6.13E-15	6.13E-15	6.13E-15	6.13E-15	6.13E-15	6.13E-15	6.13E-15	6.13E-15	6.13E-15	6.13E-15
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.80E-15	4.73E-15	4.73E-15	4.73E-15	4.73E-15	4.73E-15	4.73E-15	4.73E-15	4.73E-15	4.73E-15	4.73E-15	4.73E-15
Y(4)=2.750E-03	0.00E+00	1.59E-20	1.59E-20	1.59E-20	1.59E-20	1.59E-20	5.34E-17	3.82E-15	3.51E-15	3.51E-15	3.51E-15	3.51E-15	3.51E-15	3.51E-15	3.51E-15	3.51E-15	3.51E-15	3.51E-15	3.51E-15	3.51E-15
Y(3)=1.500E-03	0.00E+00	1.59E-20	1.59E-20	1.59E-20	1.59E-20	1.59E-20	3.26E-17	1.15E-15	1.85E-15	1.85E-15	1.85E-15	1.85E-15	1.85E-15	1.85E-15	1.85E-15	1.85E-15	1.85E-15	1.85E-15	1.85E-15	1.85E-15
Y(2)=5.000E-04	0.00E+00	1.59E-20	1.59E-20	1.59E-20	1.59E-20	1.59E-20	2.08E-17	5.91E-16	1.31E-15	1.31E-15	1.31E-15	1.31E-15	1.31E-15	1.31E-15	1.31E-15	1.31E-15	1.31E-15	1.31E-15	1.31E-15	1.31E-15
Y(1)=0.300E+00	0.00E+00	1.59E-20	1.59E-20	1.59E-20	1.59E-20	1.59E-20	2.08E-17	5.91E-16	1.31E-15	1.31E-15	1.31E-15	1.31E-15	1.31E-15	1.31E-15	1.31E-15	1.31E-15	1.31E-15	1.31E-15	1.31E-15	1.31E-15

X(IX) 1= 0.000 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207 10= 0.210

FIELD VALUES OF H20	H20	H20	H20	H20	H20	H20	H20	H20	H20	H20	H20	H20	H20	H20	H20	H20	H20	H20	H20	H20
Y(10)=9.000E-03	8.36E-02	8.36E-02	8.36E-02	8.35E-02	8.01E-02	3.38E-03	2.19E-04	3.71E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05
Y(9)=8.000E-03	8.36E-02	8.36E-02	8.36E-02	8.35E-02	8.01E-02	3.38E-03	2.19E-04	3.71E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05
Y(8)=6.750E-03	8.36E-02	8.36E-02	8.36E-02	8.35E-02	8.02E-02	3.48E-03	2.55E-04	4.20E-05	2.25E-05	2.25E-05	2.25E-05	2.25E-05	2.25E-05	2.25E-05	2.25E-05	2.25E-05	2.25E-05	2.25E-05	2.25E-05	2.25E-05
Y(7)=4.750E-03	8.36E-02	8.36E-02	8.36E-02	8.35E-02	8.04E-02	3.70E-03	3.38E-04	4.75E-05	2.17E-05	2.17E-05	2.17E-05	2.17E-05	2.17E-05	2.17E-05	2.17E-05	2.17E-05	2.17E-05	2.17E-05	2.17E-05	2.17E-05
Y(6)=3.750E-03	8.36E-02	8.36E-02	8.36E-02	8.35E-02	8.04E-02	3.76E-03	3.61E-04	3.62E-05	1.73E-05	1.73E-05	1.73E-05	1.73E-05	1.73E-05	1.73E-05	1.73E-05	1.73E-05	1.73E-05	1.73E-05	1.73E-05	1.73E-05
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.20E-05	1.34E-05	1.34E-05	1.34E-05	1.34E-05	1.34E-05	1.34E-05	1.34E-05	1.34E-05	1.34E-05	1.34E-05	1.34E-05
Y(4)=2.750E-03	0.00E+00	4.50E-11	4.50E-11	4.50E-11	4.50E-11	4.50E-11	1.51E-07	1.08E-05	9.91E-06	9.91E-06	9.91E-06	9.91E-06	9.91E-06	9.91E-06	9.91E-06	9.91E-06	9.91E-06	9.91E-06	9.91E-06	9.91E-06
Y(3)=1.500E-03	0.00E+00	4.50E-11	4.50E-11	4.50E-11	4.50E-11	4.50E-11	9.22E-08	3.26E-06	5.24E-06	5.24E-06	5.24E-06	5.24E-06	5.24E-06	5.24E-06	5.24E-06	5.24E-06	5.24E-06	5.24E-06	5.24E-06	5.24E-06
Y(2)=5.000E-04	0.00E+00	4.50E-11	4.50E-11	4.50E-11	4.50E-11	4.50E-11	5.87E-08	1.67E-06	3.69E-06	3.69E-06	3.69E-06	3.69E-06	3.69E-06	3.69E-06	3.69E-06	3.69E-06	3.69E-06	3.69E-06	3.69E-06	3.69E-06
Y(1)=0.300E+00	0.00E+00	4.50E-11	4.50E-11	4.50E-11	4.50E-11	4.50E-11	5.87E-08	1.67E-06	3.69E-06	3.69E-06	3.69E-06	3.69E-06	3.69E-06	3.69E-06	3.69E-06	3.69E-06	3.69E-06	3.69E-06	3.69E-06	3.69E-06

X(IX) 1= 0.000 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207 10= 0.210

ORIGINAL PAGE IS
OF POOR QUALITY

FIELD VALUES OF	O									
Y(10)=9.000E-03	1.27E-07	1.27E-07	2.23E-07	3.59E-07	3.08E-07	1.89E-16	1.23E-17	2.08E-18	1.29E-18	1.29E-18
Y(9)=8.000E-03	1.27E-07	1.27E-07	2.23E-07	3.59E-07	3.08E-07	1.89E-16	1.23E-17	2.08E-18	1.29E-18	1.29E-18
Y(8)=6.750E-03	1.30E-07	1.30E-07	2.29E-07	3.68E-07	3.18E-07	1.95E-16	1.43E-17	2.35E-18	1.26E-18	1.26E-18
Y(7)=4.750E-03	1.30E-07	1.30E-07	2.28E-07	3.68E-07	3.29E-07	2.00E-16	1.90E-17	2.66E-18	1.22E-18	1.22E-18
Y(6)=3.750E-03	1.27E-07	1.27E-07	2.23E-07	3.59E-07	3.28E-07	2.11E-16	2.03E-17	2.03E-18	9.72E-19	9.72E-19
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.24E-18	7.50E-19	7.50E-19
Y(4)=2.750E-03	0.00E+00	2.52E-24	2.52E-24	2.52E-24	2.52E-24	2.52E-24	8.47E-21	6.06E-19	5.56E-19	5.56E-19
Y(3)=1.500E-03	0.00E+00	2.52E-24	2.52E-24	2.52E-24	2.52E-24	2.52E-24	5.17E-21	1.83E-19	2.94E-19	2.94E-19
Y(2)=5.000E-04	0.00E+00	2.52E-24	2.52E-24	2.52E-24	2.52E-24	2.52E-24	3.29E-21	9.36E-20	2.07E-19	2.07E-19
Y(1)=0.000E+00	0.00E+00	2.52E-24	2.52E-24	2.52E-24	2.52E-24	2.52E-24	3.29E-21	9.36E-20	2.07E-19	2.07E-19
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF	OH									
Y(10)=9.000E-03	2.28E-05	2.28E-05	3.21E-05	4.29E-05	3.85E-05	2.55E-11	1.66E-12	2.80E-13	1.74E-13	1.74E-13
Y(9)=8.000E-03	2.28E-05	2.28E-05	3.21E-05	4.29E-05	3.85E-05	2.55E-11	1.66E-12	2.80E-13	1.74E-13	1.74E-13
Y(8)=6.750E-03	2.31E-05	2.31E-05	3.26E-05	4.36E-05	3.92E-05	2.62E-11	1.93E-12	3.17E-13	1.70E-13	1.70E-13
Y(7)=4.750E-03	2.31E-05	2.31E-05	3.26E-05	4.35E-05	4.01E-05	2.79E-11	2.55E-12	3.59E-13	1.64E-13	1.64E-13
Y(6)=3.750E-03	2.28E-05	2.28E-05	3.21E-05	4.29E-05	4.00E-05	2.84E-11	2.73E-12	2.73E-13	1.31E-13	1.31E-13
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.66E-13	1.01E-13	1.01E-13
Y(4)=2.750E-03	0.00E+00	3.40E-19	3.40E-19	3.40E-19	3.40E-19	3.40E-19	1.14E-15	8.15E-14	7.48E-14	7.48E-14
Y(3)=1.500E-03	0.00E+00	3.40E-19	3.40E-19	3.40E-19	3.40E-19	3.40E-19	6.96E-16	2.46E-14	3.96E-14	3.96E-14
Y(2)=5.000E-04	0.00E+00	3.40E-19	3.40E-19	3.40E-19	3.40E-19	3.40E-19	4.43E-16	1.26E-14	2.79E-14	2.79E-14
Y(1)=0.000E+00	0.00E+00	3.40E-19	3.40E-19	3.40E-19	3.40E-19	3.40E-19	4.43E-16	1.26E-14	2.79E-14	2.79E-14
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF	PR									
Y(10)=9.000E-03	1.86E-01	1.86E-01	1.86E-01	1.86E-01	1.78E-01	7.50E-03	4.87E-04	8.25E-05	5.11E-05	5.11E-05
Y(9)=8.000E-03	1.86E-01	1.86E-01	1.86E-01	1.86E-01	1.78E-01	7.50E-03	4.87E-04	8.25E-05	5.11E-05	5.11E-05
Y(8)=6.750E-03	1.86E-01	1.86E-01	1.86E-01	1.86E-01	1.70E-01	7.72E-03	5.67E-04	9.33E-05	5.00E-05	5.00E-05
Y(7)=4.750E-03	1.86E-01	1.86E-01	1.86E-01	1.86E-01	1.79E-01	8.22E-03	7.52E-04	1.06E-04	4.82E-05	4.82E-05
Y(6)=3.750E-03	1.86E-01	1.86E-01	1.86E-01	1.86E-01	1.79E-01	8.34E-03	8.03E-04	8.04E-05	3.85E-05	3.85E-05
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.89E-05	2.97E-05	2.97E-05
Y(4)=2.750E-03	0.00E+00	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	3.35E-07	2.40E-05	2.20E-05	2.20E-05
Y(3)=1.500E-03	0.00E+00	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	2.05E-07	7.25E-06	1.16E-05	1.16E-05
Y(2)=5.000E-04	0.00E+00	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.30E-07	3.71E-06	8.20E-06	8.20E-06
Y(1)=0.000E+00	0.00E+00	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.30E-07	3.71E-06	8.20E-06	8.20E-06
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF	TFI	TEM									
Y(10)=9.000E-03	6.30E+02	6.38E+02	7.39E+02	7.63E+02	6.86E+02	6.45E+02	6.29E+02	6.23E+02	6.20E+02	6.19E+02	
Y(9)=8.000E-03	1.60E+03	1.48E+03	1.73E+03	1.77E+03	1.76E+03	4.22E+02	3.53E+02	3.47E+02	3.45E+02	6.18E+02	
Y(8)=6.750E-03	1.60E+03	1.48E+03	1.73E+03	1.78E+03	1.77E+03	4.23E+02	3.53E+02	3.46E+02	3.44E+02	6.18E+02	
Y(7)=4.750E-03	1.60E+03	1.48E+03	1.73E+03	1.78E+03	1.77E+03	4.27E+02	3.55E+02	3.45E+02	3.43E+02	6.18E+02	
Y(6)=3.750E-03	1.60E+03	1.68E+03	1.73E+03	1.77E+03	1.77E+03	4.20E+02	3.55E+02	3.44E+02	3.42E+02	6.18E+02	
Y(5)=3.250E-03	4.89E+02	4.89E+02	5.11E+02	5.21E+02	4.54E+02	4.12E+02	4.04E+02	3.43E+02	3.42E+02	6.18E+02	
Y(4)=2.750E-03	2.75E+02	2.97E+02	3.15E+02	3.33E+02	3.40E+02	3.41E+02	3.42E+02	3.42E+02	3.42E+02	6.18E+02	
Y(3)=1.500E-03	2.75E+02	2.93E+02	3.10E+02	3.28E+02	3.36E+02	3.39E+02	3.40E+02	3.40E+02	3.41E+02	6.17E+02	
Y(2)=5.000E-04	2.75E+02	2.92E+02	3.08E+02	3.26E+02	3.35E+02	3.38E+02	3.39E+02	3.40E+02	3.40E+02	6.17E+02	
Y(1)=0.000E+00	2.75E+02	2.92E+02	3.08E+02	3.26E+02	3.35E+02	3.38E+02	3.39E+02	3.40E+02	3.40E+02	6.17E+02	
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210	

FIELD VALUES OF	P	P								
Y(9)=8.000E-03	-0.16E+01	-7.80E+01	-7.52E+01	-6.63E+01	-6.61E+01	-6.65E+01	-6.67E+01	-5.68E+01		
Y(8)=6.750E-03	-0.16E+01	-7.80E+01	-7.52E+01	-6.63E+01	-6.60E+01	-6.63E+01	-6.87E+01	-5.82E+01		
Y(7)=4.750E-03	-0.16E+01	-7.80E+01	-7.52E+01	-6.63E+01	-6.60E+01	-6.64E+01	-6.95E+01	-5.78E+01		
Y(6)=3.750E-03	-0.16E+01	-7.80E+01	-7.52E+01	-6.63E+01	-6.60E+01	-6.63E+01	-6.99E+01	-5.60E+01		
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-7.05E+01	-5.46E+01		
Y(4)=2.750E-03	2.35E-01	-1.99E+01	-3.76E+01	-5.62E+01	-6.32E+01	-6.65E+01	-6.88E+01	-5.29E+01		
Y(3)=1.500E-03	2.37E-01	-1.99E+01	-3.76E+01	-5.62E+01	-6.32E+01	-6.65E+01	-6.82E+01	-5.10E+01		
Y(2)=5.000E-04	0.00E+00	-1.99E+01	-3.76E+01	-5.62E+01	-6.32E+01	-6.65E+01	-6.79E+01	-5.08E+01		
X(IX)	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207		

FIELD VALUES OF	RHO	RHO									
Y(10)=9.000E-03	4.01E-01	4.01E-01	3.90E-01	3.81E-01	3.83E-01	1.60E+00	1.91E+00	1.94E+00	1.95E+00	2.54E+00	
Y(9)=8.000E-03	4.01E-01	4.01E-01	3.90E-01	3.81E-01	3.83E-01	1.60E+00	1.91E+00	1.94E+00	1.95E+00	2.54E+00	
Y(8)=6.750E-03	4.00E-01	4.00E-01	3.89E-01	3.80E-01	3.82E-01	1.59E+00	1.91E+00	1.95E+00	1.96E+00	2.54E+00	
Y(7)=4.750E-03	4.00E-01	4.00E-01	3.89E-01	3.80E-01	3.81E-01	1.58E+00	1.90E+00	1.95E+00	1.96E+00	2.54E+00	
Y(6)=3.750E-03	4.01E-01	4.01E-01	3.90E-01	3.81E-01	3.82E-01	1.57E+00	1.90E+00	1.96E+00	1.97E+00	2.54E+00	
Y(5)=3.250E-03	2.45E+00	2.45E+00	2.45E+00	2.45E+00	2.45E+00	2.45E+00	2.45E+00	1.97E+00	1.97E+00	2.54E+00	
Y(4)=2.750E-03	2.52E+00	2.28E+00	2.14E+00	2.02E+00	1.98E+00	1.97E+00	1.97E+00	1.97E+00	1.97E+00	2.54E+00	
Y(3)=1.500E-03	2.52E+00	2.30E+00	2.17E+00	2.05E+00	2.00E+00	1.99E+00	1.98E+00	1.98E+00	1.98E+00	2.54E+00	
Y(2)=5.000E-04	1.40E+00	2.26E+00	2.18E+00	2.06E+00	2.01E+00	1.99E+00	1.99E+00	1.98E+00	1.98E+00	2.54E+00	
Y(1)=0.000E+00	1.40E+00	2.26E+00	2.18E+00	2.06E+00	2.01E+00	1.99E+00	1.99E+00	1.98E+00	1.98E+00	2.54E+00	
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210	

FIELD VALUES OF	EMU	EMU									
Y(10)=9.000E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	
Y(9)=8.000E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	
Y(8)=6.750E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	
Y(7)=4.750E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	
Y(6)=3.750E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	
Y(5)=3.250E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	
Y(4)=2.750E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	
Y(3)=1.500E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	
Y(2)=5.000E-04	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	
Y(1)=0.000E+00	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210	

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APPENDIX E

UPDATE TO COMPUTE THE STANTON NUMBERS

E.1 Introduction

Appendix E is concerned with the calculation of the Stanton numbers. The basic theoretical background may be found in detail in Ref. 7. Therefore only a brief account is given here.

E.2 Theory

When the shear stress is uniform through a Couette-flow layer (which implies negligible pressure gradient and mass transfer), when the fluid properties (apart from turbulence effects on transport) are uniform, when the wall is smooth, and when the Reynolds number R is sufficiently high ($>11.5^*$), the following relations result from integrating the equations:

$$s = \left[\kappa / \ln (ERs^{\frac{1}{2}}) \right]^2 \quad (E-1)$$

$$S = s / \left[\sigma_t (1 + s^{\frac{1}{2}} P) \right] \quad (E-2)$$

$$H = \sigma_t \quad (E-3)$$

where: s is the shear-stress coefficient ($=\tau/\rho u^2$).

S is the Stanton number.

H is the recovery factor.

E is the constant in the log. wall-shear-stress expression.

R is the Reynolds number ($=\rho u y / \mu$).

and P is an integration constant.

* This value is derived by equating the laminar and turbulent expressions for shear stress and solving for y^+ (the well-known non-dimensional distance) I.E. it represents the point where the two shear stress curves intersect.

E can be taken as 9.0 (see Ref. 7), while P is a function of the laminar Prandtl-Schmidt number σ and its supposed turbulent counterpart, σ_t ; the latter function is fitted quite well by the relation:

$$9.0(\sigma/\sigma_t-1) (\sigma_t/\sigma)^{\frac{1}{4}} \quad (E-4)$$

(see Ref. 13).

These relations are known to fit experimental data quite well in situations for which the assumptions apply, e.g. fully-developed turbulent pipe flows, and turbulent boundary layers on flat plates. Equation (E-4) should not be used for σ values below 0.5.

E.3 Computational details

The only routines requiring modification for the six Stanton numbers* calculation are SOURCE and WALL.

The first business of WALL is to calculate indices, properly locating the wall under consideration. Thereafter, if laminar flow is indicated by R being less than 132.25 ($\approx 11.5^2$), the laminar-flow velocity sequence is sought at statement number 19 for velocity and at statement number 410 for enthalpy. It will not be hard for the reader to recognise, in these two program passages, the FORTRAN equivalents of the formulae which are given above.

Because of the fact that equation (E-1) contains s on both sides, iterative solution is needed; this is the reason for the DO.17 loop which is left if the number of iterations (NIT) equals 11 or $s^{\frac{1}{2}}$ differs by less than 0.0001 from its previous value. Then the Stanton number is calculated

* I.E. Stanton numbers at inner surface of end wall, at outer surface of end wall, at outer surface of inner tube, at inner surface of inner tube, at inner surface of outer tube and at outer surface of outer tube.

according to equation (E-2), and is printed out for KTEST>0. The only modifications to the subroutine SOURCE are inserted in Chapter 4, i.e. in the Chapter where the source terms for $\hat{h}$ are computed. The modifications consist of calling subroutine WALL to calculate the Stanton numbers prior to their use for the calculation of heat transfer.

E.4 Additional FORTRAN Symbols

NAME	LOCATION	TYPE	MEANING
PJAY	WALL		Jayatillaka's P function
PRRAT	WALL		Prandtl number ratio
STERM	WALL		Stanton number

E.5 Listing of modified subroutines

The listing of the two modified subroutines SOURCE and WALL follows.

```

ELU 1,2,3,3
SUBROUTINE WALL(I1,STERM,STERM1,IY,JPHI)
COMMON/COMA/ U(480),V(475),H(500),FM(500),FUE(500),FS(500,15),
1 PP(20),TEM(500),P(414),RHO(500),EMU(500),
1 DXG(25),DXU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),
2 STORE(25),SXG(25),SXU(25),X(25),XU(25),
3 A(20),AE(20),AN(20),AREAE(20),AS(20),ASNIP(20),AW(20),B(20),
4 BSNIP(20),C(20),CSNIP(20),DIFE(20),DIFEE(20),DIFN(20),
5 DIFNE(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),
6 FLOWE(20),FLOWEE(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),
7 RUYG(20),RUYV(20),RSYG(20),RSYV(20),RV(20),RVCB(20),RVSQ(20),
8 SP(20),SU(20),SYG(20),SYV(20),Y(20),YV(20),AEDDX(500),
9 ANDDY(500),AREAN(500),VOL(500),
X ARSL(25,25),PREFF(25),PRL(25),PRT(25),RSLINE(25,25),
1 IEW(25),ILAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),
2 RSREF(25),RSSUM(25),TITLE(25)
DIMENSION DIFNW(20),DIFWW(20),F(11889),FLOWNW(20),FLOWWW(20)
EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),
1 FLOWEE(1)),(DIFNW(1),DIFNE(1)),(DIFWW(1),DIFEE(1))
COMMON/COMB/
1 AK,ARRCON,BIG,CHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,
2 EPST,EQRAT,EWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,
3 FSTOIM,FUB,FUC,HFU,HW,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,
4 ISWEEP,IX,IXMON,IXPREF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,
5 IX1NY1,IX2NYU,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,
6 IYPREF,IYW,IYWM1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,
7 JS1,JS2,JTEM,JU,JV,KASE,KINPRI,KLT,KRAD,KRHOMU,KSWEET,KTEST,
8 LABPHI,LSWEEP,NSOLVE,NTOMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,
9 NXM2,NXYG,NXYP,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OXB,OXC,PJAY,
X PREEXP,PRESS,RELAXP,RF,RFSTM,RSCHK,RSMAX,R1I,R1O,R2I,R2O,
1 STOICH,TB,TC,TINY,TMAX,TMIN,UB,UC,WMIX
COMMON/HTR/ ALNR1I,ALNR1O,ALNR2I,ALNR2O,COND,EL3,
1 EMIS1O,EMIS2I,EMIS2O,EMISX1,EMISXO,REMI,RHOINF,
1 SIGMA,STXI,STXO,ST1I,ST1O,ST2I,ST2O,TINF,UINF,VINF,AREA
DATA SHALF/0.04/
K WALL=2-1/I1
I2=I1+3-2*K WALL
I3=I1+2-K WALL
IF (IY.NE.0) GO TO 10000
I=I2+IX1NY
IF (JPHI.EQ.JU) GO TO 10
IF (JPHI.EQ.JH) GO TO 400
RETURN
C
10 I=I2+IX1NYU
RUREF=RHO(I)*ABS(U(1))
RE=RUREF*DYG(I3)/EMUREF
IF (KLT.EQ.1) GO TO 19
IF (RE.LT.132.25) GO TO 19
ER=RE*EWALL
ARGMIN=11.5*EWALL
DO 17 NIT=1,11
SHALF1=SHALF
ARG=ER*SHALF
IF (ARG.LT.ARGMIN) GO TO 19
SHALF=AK/ALOG(ARG)
IF (ABS(SHALF-SHALF1).LT.0.0001) GO TO 18
17 CONTINUE
18 S=SHALF**2
STERM1=S*R(I2)*RUREF*SXU(IXU)
RETURN
19 STERM1=EMUREF*SXU(IXU)*R(I1)*RDYG(I3)

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WA000590

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-- RETURN
400 CONTINUE
  I=11+IX1NY
  IW=I-NY
  YREF=DYG(NY)
  IF(I1.EQ.IYWM1) YREF=0.5*DYG(IYW)
  IF(I1.EQ.IYWP1) YREF=0.5*DYG(IYWP1)
  RUREF=RHO(I)*0.5*ABS(U(I)+U(IW))
  IF(I1.EQ.NY) RUREF=RHOINF*UINF
  RE=RUREF*YREF/EMUREF
  IF(KLT.EQ.1) GO TO 410
  IF(RE.LT.132.25) GO TO 410
  ER=RE*EWALL
  ARGMIN=11.5*EWALL
  NIT=0
401 SHALF1=SHALF
  ARG=ER*SHALF
  IF(ARG.LT.ARGMIN) GO TO 410
  SHALF=AK/ALOG(ARG)
  IF(ABS(SHALF-SHALF1).LT.0.0001) GO TO 402
  N11=NIT+1
  IF(NIT.LT.11) GO TO 401
402 S=SHALF**2
  PRRAT=PRL(JPHI)/PRT(JPHI)
  PJAY=9.0*(PRRAT-1.0)/PRRAT**0.25
  STERM=S/(PRT(JPHI)*(1.0+AMAX1(-0.9999,PJAY*SHALF)))
  GO TO 411
410 STERM=1.0/(PRL(JPHI)*RE)
411 CONTINUE
  IF(KTEST.GT.0) WRITE(6,412) I1,IY,STERM,NTRAV
412 FORMAT(10(1H*),2I3,E20.8,I3)
  RETURN

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```

10000 I=IY+IX1NY
      IV=IY+IX1NY1
      IVS=IV-1
      IF (JPHI.EQ.JV) GO TO 200
      IF(JPHI.EQ.JH) GO TO 4000
      RETURN
200 RUREF=RHO(I)*ABS(V(IV))
    RE=RUREF*DXG(I3)/EMUREF
    IF(KLT.EQ.1) GO TO 290
    IF (RE.LT.132.25) GO TO 290
    ER=RE*EWALL
    ARGMIN=11.5*EWALL
    DO 270 NIT=1,11
      SHALF1=SHALF
      ARG=ER*SHALF
      IF (ARG.LT.ARGMIN) GO TO 290
      SHALF=AK/ALOG(ARG)
      IF (ABS(SHALF-SHALF1).LT.0.0001) GO TO 280
270 CONTINUE
280 S=SHALF**2
    STERM1=S*RUREF*SYV(IY)*RV(IY)
    RETURN
290 STERM1=EMUREF*SYV(IY)*RV(IY)*RDXG(I3)
    RETURN

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WA000790

WA000800

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4000 CONTINUE
YREF=DXG(NX)
RUREF=RHO(I)*0.5*ABS(V(IV)+V(IVS))
IF(I1.EQ.NX.OR.IX.EQ.NX) RUREF=RHOINF*VINP
RE=RUREF*YREF/EMUREF
IF(KLT.EQ.1) GO TO 4100
IF(RE.LT.132.25) GO TO 4100
ER=RE*EWALL
ARGMIN=11.5*EWALL
NIT=0

4010 SHALF1=SHALF
ARG=ER*SHALF
IF(ARG.LT.ARGMIN) GO TO 4100
SHALF=AK/ALOG(ARG)
IF(ABS(SHALF-SHALF1).LT.0.0001) GO TO 4020
NIT=NIT+1
IF(NIT.LT.11) GO TO 4010

4020 S=SHALF**2
PRKAT=PRL(JPHI)/PRT(JPHI)
PJAY=9.0*(PRKAT-1.0)/PRKAT**0.25
STERM=S/(PRT(JPHI)*(1.0+AMAX1(-0.9999,PJAY*SHALF)))
GO TO 4110

4100 STERM=1.0/(PRL(JPHI)*RE)
4110 CONTINUE
IF(KTEST.GT.0) WRITE(6,412) I1,IY,STERM,NTRAV
RETURN
END

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276

IF (UPH1.E..00) GO TO 10	S0000530
IF (UPH1.E..0V) GO TO 20	S0000540
IF (UPH1.E..0H) GO TO 40	S0000550
IF (UPH1.E..0FM) GO TO 50	S0000560
IF (UPH1.E..0FUE) GO TO 60	S0000570
IF (UPH1.E..0PP) GO TO 90	S0000580
RETURN	S0000590
C-----	S0000600
CHAPTER 2 2 2 2 2 2 SOURCE TERMS FOR U 2 2 2 2 2 2 2 2	S0000610
C-----	S0000620
10 ICONST=IX2HTU-1	S0000630
IF (KRMHML.E..0) GO TO 12	S0000640
RLXU1X=RLXU(1XU)	S0000650
RLXU11=RLXU(1XUP1)	S0000660
RSXU1X=RSXU(1XU)	S0000670
GRDXG=0.25*RDAG(1XUP1)	S0000680
C	S0000690
I=IYFM1+IX1MYU	S0000700
IL=1+IY	S0000710
IN=1+1	S0000720
INL=IN+IY	S0000730
IXU1IY=(1XU-1)*IYFM1	S0000740
IV=IYFM1+IXU1IY	S0000750
IEV=IV+IY-1	S0000760
EDVDX=(E U(1)+EMU(1E)+EMU(1I)+EMU(1IE))*(V(1EV)-V(1V))*PV(IYFM1)	S0000770
DU 11 IY=IV-IY, IYL	S0000780
I=1Y+IX1MYU	S0000790
IE=1+IY	S0000800
IW=1-IY	S0000810
IN=1+1	S0000820
INL=IN+IY	S0000830
IV=1Y+IXU1NY	S0000840
IEV=IV+IY-1	S0000850
IP=1Y+1CONST	S0000860
ILP=IP+IY-2	S0000870
DUDXW=(U(I)-U(I'))*RDXU1X	S0000880
DUDXF=(U(IE)-U(1))*RDXU11	S0000890
S1ERM=(EMU(1E)+DUDXE-LMU(1W)*DUDXW)*RSXU1X	S0000900
EDVDXS=EDVDXN	S0000910
EDVDX=(E U(1)+EMU(1E)+EMU(1I)+EMU(1IE))*(V(1EV)-V(1V))*RV(IY)	S0000920
S1ERM=S1ERM+(EDVDXN-EDVDXS)*GRDXG/AREAE(IY)	S0000930
SU(IY)=AREAE(IY)*(P(1P)-P(1EP))+0.5*S1ERM*(VOL(1)+VOL(1E))	S0000940
SP(IY)=U.J	S0000950
C----- INERTIAL UNDER-RELAXATION -----	S0000960
AFAC=0.0	S0000970
ASU=AFAC*ABS(SU(IY))	S0000980
AFACT=ASU/(ABS(U(I))+1INY)	S0000990
AFAT=1.0E3*ASU	S0001000
AFACT=AFAT/(AFACT+AFAT)	S0001010
SU(IY)=SU(IY)+AFACT*U(1)	S0001020
SP(IY)=SP(IY)-AFACT	S0001030
11 CONTINUE	S0001040

GO 13 14	S0001050
12 DO 13 1Y=1YF,IYL	S0001060
IF=1Y+ICONS	S0001070
IEP=1P+IY*2	S0001080
SO(1Y)=AREAL(IY)*(P(1P)-P(1EP))	S0001090
13 SP(1Y)=0.0	S0001100
C	S0001110
14 IF(1X0.EQ.1X0.AND.1MC.EQ.-1) GO TO 1000	S0001120
GO 13 1002	S0001130
1000 DO 1001 1Y=2,IYV	S0001140
I=1Y+1X1NYU	S0001150
SO(1Y)=SIG*U(I)	S0001160
1001 SP(1Y)=-SIG	S0001170
C-----EXTRA SOURCES DUE TO INNER TUBE.	S0001180
1002 IF (1X0.GT.1XW) RETURN	S0001190
IF (1MC.NE.1) GO TO 15	S0001200
I2=1Y*11	S0001210
I3=1Y*1	S0001220
GO TO 16	S0001230
15 I2=1Y*P1	S0001240
I3=1Y*P1	S0001250
16 I=I2+1X1*1YU	S0001260
RUREF=RHO(I)*ABS(U(I))	S0001270
RE=0.5*RUREF*DYG(I3)/EMUREF	S0001280
IF(KLT.EQ.1) GO TO 19	S0001290
IF (RE.LT.132.25) GO TO 19	S0001300
ER=RE*EWALL	S0001310
ARGMIJ=11.5*EWALL	S0001320
DO 17 HIT=1,11	S0001330
SHALF1=SHALF	S0001340
ARG=ER*SHALF	S0001350
IF (ARG.LT.ARGMIN) GO TO 19	S0001360
SHALF=ARG/ALOG(ARG)	S0001370
IF (ABS(SHALF-SHALF1).LT.0.0001) GO TO 18	
17 CONTINUE	
18 S=SHALF**2	S0001400
SP(12)=SP(12)-S*R(12)*RUREF*SXU(1XU)	S0001410
RETURN	S0001420
19 SP(12)=SP(12)-EMUREF*SXU(1XU)*R(12)/(DYG(I3)*0.5)	S0001430
RETURN	S0001440
C-----	S0001450
CHAPTER 3 3 3 3 3 3 SOURCE TERMS FOR V 3 3 3 3 3 3 3 3	S0001460
C-----	S0001470
20 ICONST=1X2*IY2-1	S0001480
IF(1X.EQ.2.AND.1MC.EQ.-1) GO TO 25	S0001490
IF (XRNHOU.EQ.0) GO TO 22	S0001500
WRXSG=0.25*RSXG(1X)	S0001510
II=1YF+1X1NY	S0001520
IV=1YF*1+1X1NY1	S0001530
EDVDY1=EM(111)*IV(IV+1)-V(IV))*RDYV(1YF)*R(1YF)	S0001540
DO 21 1Y=1YF,IYLM1	S0001550
IYF1=1YF1	S0001560

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I=IY+IX1IY
IH=I+1
IE=I+IY
INE=IC+1
I..=I- IY
IHW=I+1
IV=IY+IX1IY1
IP=IY+ICU1SI
LHOM=EMO(I)+E1I(IH)
EMOE=EMO(IH)+EMO(IE)+EMO(INE)
EMOW=EMO(IH)+EMO(IW)+EMO(IHW)
STLR=(E1IE*(U(IH)-U(I))-EMOW*(U(IHW)-U(IW)))*GRSXG*RDYG(IYP1)
EDVDYS=EDVDYI
EDVDYI=E1J(I1)*(V(IV+1)-V(IV))*RDYV(IYP1)*R(IYP1)
STLR=STLR+(EDVDYN-EDVDYS)/AREAE(IY)
VOLUME=0.5*(VOL(I)+VOL(IH))
SU(IY)=STLR*VOLUME+AREAE(I)*(P(IP)-P(IP+1))
SP(IY)=EMO*VOLUME/RVSW(IY)
C----- INERTIAL UNDER-RELAXATION -----
AFAC=0.0
ASU=AFAC*ABS(SU(IY))
AFACI=ASU/(ABS(V(IV))+I1IY)
AFAT=1.0E5*ASU
AFACT=AMIN1(AFACT,AFAT)
SU(IY)=SU(IY)+AFACI*V(IV)
SP(IY)=SP(IY)-AFACI
21 CONTINUE
RETURN
22 DO 23 IY=IYF,IYLM1
I=IY+IX1IY
IH=I+1
IE=I+IY
IP=IY+ICU1SI
SU(IY)=AREAE(I)*(P(IP)-P(IP+1))
23 SP(IY)=-.25*(E1I(I)+EMO(IH))*(VOL(I)+VOL(IH))/RVSW(IY)
RETURN
25 DO 26 IY=IYF,IYLM1
SU(IY)=0.0
26 SP(IY)=-BIG
RETURN
C-----
CHAPTER 4 4 4 4 4 4 SOURCE TERMS FOR H 4 4 4 4 4 4 4 4 4 4
C-----
40 CONTINUE
DO 400 IY=IYF,IYL
SU(IY)=0.0
400 SP(IY)=0.0
C
IF (IX.LG.IHX) GO TO 430
I=IY+IX1IY
IS=I+1
IH=I+1
IE=I+IY

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```

IW=1-IY
ISW=1.-1
IY=1.-1
I.WAL=IY+1./10Y
I.WALS=I.WAL-1
I.WALE=I.WAL+IY
I.WALW=I.WAL-IY
I.WALS=I.WAL-1
C
GRAD15=0.0
GRAD14=0.0
IF (IX.EQ.1XW) GO TO 410
AE(IY)=0.0
AI(IY)=0.0
AS(IY)=0.0
AW(IY)=0.0
AS(IY+1)=0.0
AI(IY+1)=0.0
CALL CALL(IYW+1,STEM,STEM1,0,0H)
ST11=STEM
H11=ST11*AHU(1S)*ABS(0.5*(U(1S)+U(1SW)))*CMIX
R11=SAU(1X)/(1.0/(R11+H11)+ALUR11/COND)
Q11=R11*TEM(1S)
CALL CALL(IY+1,STEM,STEM1,0,0H)
ST10=STEM
H10=ST10*AHU(1I)*ABS(0.5*(U(1I)+U(1IW)))*CMIX
R10=SAU(1X)/(1.0/(R10+H10)+ALUR10/COND)
Q10=R10*TEM(1I)
IF (IX.EQ.2) GO TO 401
IF (IX.EQ.1XW) GO TO 405
GAMMA=COUE*AREAE(IYW)
GAMMA1=GAMMA*KDXG(1XP1)
GAMMA2=GAMMA*KDXG(1X)
GCOND1=GAMMA1+GAMMAW
GCOND2=GAMMA1*TEM(1E)+GAMMA2*TEM(1W)
GO TO 410
401 GAMMA1=COUE*AREAE(IYW)*KDXG(1XP1)
GCOND1=GAMMA1
GCOND2=GAMMA1*TEM(1E)
GO TO 410
405 GAMMA1=COUE*AREAE(IYW)*KDXG(1X)
GCOND1=GAMMA1
GCOND2=GAMMA1*TEM(1W)
410 CONTINUE
GRAD11=SIGMA*(TEM(1WAL)+TEM(1))*(TEM(1WAL)**2+TEM(1)**2)
1/(1.0/(AREAN(1)*EMIS10)+REMI/AREAN(1WALS))
NRAD13=NRAD11
GRAD14=NRAD11*TEM(1)
SU(IY+1)=R11*TEM(1)-Q11
SU(IY)=GCOND2+GRAD11*TEM(1WAL)+Q11+Q10
SF(IY)=GCOND1-GRAD11-R11-R10
SU(IY+1)=R10*TEM(1)-Q10

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S0002090
 S0002100
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415 CONTINUE
CALL WALL(NYM1,STERM,STERM1,0,JH)
ST21=STERM
H21=ST21*PHU(IWALS)*ABS(0.5*(U(IWALS)+U(IWALS*W)))*CMIX
RU21= SXG(IX)/(1.0/(K21*H21)+ALNR21/COND)
Q21=RU21*TEM(IWALS)
CALL WALL(NY,STERM,STERM1,0,JH)
ST20=STERM
H20=ST20*RHU1INF*ABS(UINF)*CMIX
RU20= SXG(IX)/(1.0/(K20*H20)+ALNR20/COND)
Q20=RU20*TIHF
IF(IX.EQ.2) GO TO 416
CAREA=CONC*WAREA
GAMAE=CAREA*ROXG(IXP1)
GAMAW=CAREA*ROXG(IX)
GCOND1=GAMAE+GAMAW
GCOND2=GAMAE*TEM(IWAL)+GAMAW*TEM(IWALW)
GO TO 420
416 GAMAE=COND*WAREA*ROXG(IXP1)
GCOND1=GAMAE
GCOND2=GAMAE*TEM(IE)
420 GRAD01=SIGMA*SXG(IX)*K20*EMIS20*(TIHF+TEM(IWAL))
1 *(TIHF**2+TEM(IWAL)**2)
SU(NY)=GCOND2+GRAD14+GRAD01*TIHF+Q21+Q20
SP(NY)=-GCOND1-GRAD13-GRAD01-RU21-RU20
SU(NYM1)=RU21*TEM(IWAL)-Q21
C
IF(IX.NE.NXM1) RETURN
HEL3C=0.5*EL3/COND
DO 425 IY=2,NYM1
I=IY+IX1NY
IE=I+NY
IV=IY+IX1NY1
IVS=IV-1
CALL WALL(NXM1,STERM,STERM1,IY,JH)
STX1=STERM
HX1=STX1*RHU(I)*ABS(0.5*(V(IV)+V(IVS)))*CMIX
UX1=AREAE(IY)/(1.0/HX1+HEL3C)
QX1=UX1*(TEM(I)-TEM(IE))
425 SU(IY)=SU(IY)-QX1
RETURN
430 DO 435 IY=IYF,IYL
I=IY+IX1NY
IV=IY+IX1NY1
IW=I-NY
IVW=IV-NY11
IVSW=IVW-1
IW=I+1
IS=I-1
CONDL=CONC*EL3
IF(IY.EQ.NY) GO TO 431
CALL WALL(NXM1,STERM,STERM1,IY,JH)

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S0002580
S0002590

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STX1=STERM
HX1=STX1*RHO(1Y)*ABS(0.5*(V(1VH)+V(1VSH)))*CMIX      S0003010
UX1=AREAE(1Y)/(1.0/HX1+HEL3C)                          S0003020
OX1=UX1*TEM(1Y)                                          S0003030
GAMMA=COROL/ALOG(R(1Y+1)/R(1Y))                        S0003040
GO TO 432                                                S0003050
431 UX1=0.0                                              S0003060
    JX1=0.0                                              S0003070
    GAMMA=0.0                                            S0003080
    CALL WALL(HX,STERM,STERM1,1Y,JH)
    STX0=STERM
    HX0=STX0*RHO(1Y)*ABS(V(1YH))*CMIX                  S0003090
    UX0=AREAE(1Y)/(1.0/HX0+HEL3C)                      S0003100
    GO TO 436                                            S0003110
432 CALL WALL(HX,STERM,STERM1,1Y,JH)
    STX0=STERM
    HX0=STX0*RHO(1Y)*ABS(V(1YH))*CMIX                  S0003120
    UX0=AREAE(1Y)/(1.0/HX0+HEL3C)                      S0003130
433 QX0=UX0*TIME                                         S0003140
    IF(1Y.EQ.2) GO TO 436                               S0003150
    GAMMA=COROL/ALOG(R(1Y)/R(1Y-1))                    S0003160
    GO TO 434                                            S0003170
433 GAMMA=0.0                                            S0003180
434 AM(1Y)=GAMMA
    AS(1Y)=GAMMA
    GRAD1=SIGMA*AREAE(1Y)*(EMISX1+EMISX0)*(TIME+TEM(1Y))
    1 * (TIME**2+TEM(1Y)**2)                            S0003200
    AS(1Y)=0.0                                          S0003210
    SU(1Y)=GRAD1*TIME+OX1+QX0                          S0003220
    SP(1Y)=-GRAD1-UX1-UX0                               S0003230
    GAMMA=COROL*AREAE*ROAG(1Y)                        S0003240
    SU(1Y)=SU(1Y)+GAMMA*TEM(1X1NY)                    S0003250
    SP(1Y)=SP(1Y)-GAMMA                                S0003260
    CALL WALL(1Y,STERM,STERM1,0,JH)                    S0003270
    ST20=STERM                                          S0003280
    H20=ST20*RHO(1Y)*ABS(V(1YH))*CMIX                  S0003290
    RU20=EL3/(1.0/(R20*H20)+ALNR20/COROL)              S0003300
    Q20=RU20*TIME                                       S0003310
    SU(1Y)=SU(1Y)+Q20                                  S0003320
    SP(1Y)=SP(1Y)-RU20                                 S0003330
    RETURN                                              S0003340
C-----S0003350
CHAPTER 5 5 5 5 5 SOURCE TERMS FOR MIXTURE FRACTION 5 5 5 5 5 S0003360
C-----S0003370
    50 DO 52 1Y=1YF,1YL                                S0003380
        SU(1Y)=0.0                                       S0003390
    52 SP(1Y)=0.0                                       S0003400
        RETURN                                           S0003410
C-----S0003420
CHAPTER 6 6 6 6 6 6 SOURCE TERMS FOR FUEL 6 6 6 6 6 6 S0003430
C-----S0003440
    60 T1=PKEXP*PKESS**2                                S0003450

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PAGE 0008

DO 62 IY=IYF,IYL	S0003460
I=IY+IX1IY	S0003470
FUBKNT=AMAX1(0.0,(FM(I)-FSTOIC)*RFSIN)	S0003480
FUEX=FUE(I)-FUBKNT	S0003490
IF (FUEX.GT.0.0) GO TO 61	S0003500
SP(IY)=-BIG	S0003510
GO TO 62	S0003520
61 FOX=AMAX1(TINY,STOICH*(FUE(I)-(FM(I)-FSTOIC)*RFSIN))	S0003530
SP(IY)=-T1*EXP(-ARRCON/TEM(I))*VOL(I)*FOX*FUE(I)/FUEX	S0003540
62 SU(IY)=-SP(IY)*FUBKNT	S0003550
RETURN	S0003560
C-----	S0003570
CHAPTER 7 7 7 7 7 7 SOURCE TERMS FOR PA 7 7 7 7 7 7 7	S0003580
C-----	S0003590
90 ERROR=0.0	S0003600
IF (IX.EQ.2.AND.INC.EQ.-1) GO TO 93	S0003610
DO 92 IY=IYF,IYL	S0003620
C ERROR MASS SOURCES	S0003630
ESMASS=-FLOWN(IY)+FLOWN(IY-1)-FLOWE(IY)+FLOWW(IY)	S0003640
SU(IY)=ESMASS	S0003650
SP(IY)=0.0	S0003660
92 ERROR=ERROR+ABS(ESMASS)	S0003670
IF (IX.NE.IXM1.OR.INC.NE.1) GO TO 95	S0003680
SU(IYL)=0.0	S0003690
SP(IYL)=-BIG	S0003700
GO TO 95	S0003710
C-----OUTLET BOUNDARY - UNIFORM PRESSURE ASSUMED.	S0003720
93 DO 94 IY=IYF,IYL	S0003730
SU(IY)=0.0	S0003740
94 SP(IY)=-BIG	S0003750
95 RSLINE(IX,JPP)=ERROR/KSREF(JPP)	S0003760
AKSL(IX,JPP)=ABS(RSLINE(IX,JPP))	S0003770
RETURN	S0003780
END	S0003790

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